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Processes and Landforms in the South American Coast.

Jorge Xavier Da silva
Louisiana State University and Agricultural & Mechanical College

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PROCESSES AND LANDFORMS IN THE SOUTH AMERICAN COAST

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Jorge Xavier da Silva
B. S., Universidade do Brasil, 1959
M. S., Louisiana State University, 1963
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To all those who helped me, including my wife Aurenice, I dedicate this work.

TABLE OF CONTENTS

FIGURES

ABSTRACT

Quantifying procedures for the study of some aspects of process-form interactions between terrestrial and marine forces, on a continental scale, are presented in this study. Indexes and ratios representative of these forces and interactions are quantitative elements obtained from standardized measurements made along the South American coast. These quantitative elements are applied to descriptions of types of coastal environments found around the continent. Close association between the presence of beaches and wave energy at the shore, tidal ranges, presence of crenulations, highlands, and shoals is statistically established through the use of multiple-regression screening computer schemes. Conclusions are drawn concerning the internal relations among the involved variables and the validity and possible utilization of the adopted procedures.

INTRODUCTION

The aim of this study is to develop procedures for quantifying some aspects of process-form interactions and relationships between terrestrial and marine forces on a continental scale. The South American coast is used because it exhibits a wide range of coastal variability, extending from low deltas to fiords, set in a climatic framework which spans tropic to subarctic conditions. Specifically, the objective is to develop measurement techniques and to apply statistical procedures to a limited number of pertinent variables, the values of which can be standardized at a large scale. To accomplish this goal a systematic investigation was made of the literature and maps of beaches, shoals, rocky terraces, coastline configurations, lowlands, and highlands, and relationships were established between those features and wave climates and tidal ranges. Types of coastal environments are analyzed in terms of interactions between landforms and processes, and procedures for quantifying both categories were developed specifically for this investigation. This study will attempt to establish statistically that the occurrence of beaches at the coast on a continental scale is related mainly to interacting effects between waves and tides, coastline configuration, and presence of highlands and shore shoals along the coast.

STATE OF KNOWLEDGE

Coastal environments are the product of a complex association of mainly marine and terrestrial elements. Many studies of these associations have been directed toward coastal classification, which is not the goal of this dissertation. However, because some concepts stemming from classification studies provide background information, they will be briefly treated.

Perhaps the most widely known coastal categorization of its time was Johnson's genetic classification (1919), which used landforms as its basis. Johnson designated coasts as emergent, submergent, or compound. The third category includes coasts which arise from combinations of the emergent and submergent types. Strong criticism of this classification is that too many coasts fall into the compound category. Coasts of emergence are also questionable because Recent sea level rise has caused general submergence of the world's coasts. In only a few areas of rias and fiords could the emergent coastal type be found.

Considering all coasts virtually as submergent, Shepard's classification (Shepard, 1937; 1948; 1963) directly opposed Johnson's earlier view of relative movement of sea level as the commanding element of a coastal classification. Shepard made use of the concept of terrestrial and marine agencies which dominated and characterized coasts. He used landforms to recognize his coast types (ria coasts, drowned karst topography, etc.) but placed them inside a geomorphologic process context (land erosion coasts, wave erosion coasts, marine deposition coasts, etc.).

Considering an adequate dichotomy of terrestrial and marine agencies, Shepard's classification stands useful for descriptive and associative studies of coasts because it can be applied to aerial photos, topographic maps, and coastal charts of several scales.

Another well-known classification is Valentin's (1952). It is based on a horizontal view of present retreat or advance of coastlines. The advance of a coast may be caused by emergence or progradation, and retreat, by submergence or retrogression. The main point of this classification is its noncyclical character; i.e., it does not consider stages. Instead, it recognizes that constant changes caused by continually active forces are significantly shaping coastal landforms. But this is probably also a weak point inasmuch as coasts do afford, in many cases, insufficient or controversial evidence of the actions of its modifying forces.

Price (1955) presents a detailed and valuable shoreline classification under the form of a double-entry chart; correlations are easily established between several levels of wave energy, expressed as classes, and shoreline features. This classification emerged from earlier studies on the Gulf of Mexico (Price, 1954). Price considered both shoreline and shelf conditions, and his classes were grouped according to high, medium, low, and zero wave energy levels. As a direct attempt to correlate coastal and shelf features to wave energy, Price's classification is a definite step toward the use of integrated perspectives, based on process-response interactions, in coastal studies. In this respect he was ahead of his time.

McGill (1958) created a morphologic classification of coasts which is primarily presented on a map. It is based on dominant processes causing subaerial erosion or deposition along the coast, and it associates those processes with the coastal topographic and geologic conditions. Terms such as plateaus, hills, and constructional plains are applied to relatively short segments of coast at a scale of 1:25,000,000. The distribution of the features is indicated by the coastal outline itself. Aimed at being "only a first approximation" (McGill, 1958, p. 405), this classification can provide detailed description of segments of coastlines.

Davies (1964) presents a classification of coasts based exclusively on marine agencies, namely waves and tides. Classes of coasts based on waves are the storm wave environment, the swell environment, and the low-energy environment. These coastal types are described practically only in terms of the destructive and constructive activity of waves (Davies, 1964, p. 137). Considering the effects of tides, three other classes are created in this classification: a microtidal environment, with a tidal range of less than 6 feet; a macrotidal environment, with tidal ranges higher than 12 feet; and a mesotidal environment. These classes are conjugated with the wave classes, and a brief description of coastal characteristics is given (Davies, 1964, p. 139). No attempt is made to associate these marine energy elements with terrestrial elements such as geologic structure or lithology.

C. S. Alexander, working on the northeast coast of Tanganyika, used maps of several scales in the creation of a method of descriptive shore classification (Alexander, 1966). Symbols along the coastline are used in this paper in a manner similar to that used in the present study. Alexander believes that increasing knowledge about coastal processes will render present genetic classifications unsatisfactory. His classification, however, does not allow an objective treatment of the joint effects of the geometry and material constitution of the shore zone. It permits only their description inasmuch as the features do not have a numeric value attached to them, except for beach gradient and cliff height. They are not treated numerically as a set, a composite of relationships. The point to be made here is that increasing knowledge about coastal features must come from consideration of the combined effects of the coast-forming factors, and the mere creation of categories does not facilitate the task of bringing into light the significant correlations among the mentioned factors.

Inman and Nordstrom (1971) present thought-provoking classifications of coasts in which they attempt to establish relationships between tectonic displacements of the earth's crust and the morphologic characteristics of the continental shelves and coasts. Tectonically, the coasts are classed as (a) collision coasts when they are in areas where tectonic plates are incident upon each other; (b) trailing edge coasts when they are in continental edges opposite to the collision edge (Amero type), or are near beginning tectonic separation centers (Neo-trailing-edge type), or are in margins of the continent which are undergoing displacements along both edges (Afro-trailing-edge type); or (c) marginal seacoasts when they front on marginal seas and are protected by island arcs.

The morphologic classification of Inman and Nordstrom is essentially descriptive, although some associations are made with the tectonic coastal classification and with evolutionary stages. For example, "with cessation of collision and maturity of erosion cycle mountainous coasts grade into hilly coasts" (1971, p. 17). The association between morphologic and tectonic classes is further pursued through the presentation of a generalized statistical table in which it can be seen, for example, that mountainous coasts dominate along collision coasts (1971, p. 19). Several difficulties arise in relation to the tectonic classification itself (as acknowledged by the authors, p. 16), the main one being the lack of sufficient data about the tectonics of many areas of the globe.

An effort toward a general descriptive coastal classification is being undertaken by Dolan *et al.* (1972). In this classification environmental factors are considered, such as wave climate, tidal regime, oceanic water masses, air masses, tides, topography, and lithology of the coasts. A dominant shoreline process classification is presented in the chapter on material response context. Included are marine, fluvial, biologic, and mass wasting processes (1972, p. 27).

The basic characteristic of most coastal classifications is that features are combined graphically on maps or in terms of a geomorphologic (or environmental) hierarchy of processes and forms. Usually the presence or absence of a feature, or set of features, is used as a criterion for types of coasts. As knowledge about coastal environments increases, many of the criteria related to the genesis of the landform become obsolete, and so the classification loses validity. Descriptive criteria, when associated with processes, seem to have greater applicability, although problems of scale of the coastline to be analyzed always require a variable degree of abstraction in the application of descriptive classifications.

It is apparent from the above coastal classifications that there is a general lack of detailed geomorphologic knowledge and, in particular, information on coupling mechanisms which link processes and forms on both large and small scales.

In coastal morphologic literature and related fields there has been emphasis on studies that consider the relationships between shoreline features and marine processes. Only those studies which are relevant to this investigation will be treated here. Many of these detailed studies consider only two-dimensional changes along beach and nearshore profiles in relation to wave activity (Inman and Filloux, 1960; Bascom, 1960; Sonu and van Beek, 1971).

Studies which are particularly relevant to quantifying aspects of wave and tide processes are the following: Bauer (1933) presented an overview of tides around the world; Bretschneider and Reid (1954) showed effects of refraction and bottom friction on wave heights; Bascom (1959) presented a descriptive account of waves; King (1959) dealt with relations between beach topography, tides, and waves; Shepard (1963) considered marine processes in his coastal classification; Wiegel (1964) studied the physics and numeric values on wave energy and refraction indexes. Lewis (1938) showed the relationship between curved shorelines and dominant direction of breakers; Davies (1959) investigated effects of wave refraction on beach curvature on Tasmanian beaches; Edwards (1951) studied shoreline erosion and formation of platforms by wave action; Hoyle and King (1958) considered the origin of beaches in relation to wave action and geologic structure and lithology; and Tanner (1958 and 1961) related river sediment supply and wave activity to beach equilibrium.

Sonu and Russell (1966) significantly contributed to the field in their studies on the effects of waves and related currents on nearshore topography, which emphasized the importance of a three-dimensional approach; Sonu et al. (1966) further advanced three-dimensional concepts and quantitative procedures for analysis of the relations between longshore currents and nearshore topography.

A study which contributed most directly to understanding of the relations between wave climate and coastal landforms was Russell's investigation of South American marine energy (1969). Coleman and Wright (1971) used wave climate as a significant marine input to deltaic systems, and they later applied these concepts to seven major world deltas (Wright and Coleman, in press).

Harrison et al. (1965) used multiple-regression screening techniques in a detailed study of beach processes and responses at Virginia Beach, Virginia. Their data were obtained under controlled field conditions, and reduction of the data resulted in linear multiple-regression predictive equations of the same type as those used in this dissertation. Multiple-regression techniques are widely used in the geosciences (Krumbein and Graybill, 1965; Silvester and La Cruz, 1970). The latter is a quantitative study of the predominant forces acting in the formation of deltas; a screening procedure similar to the one used in this dissertation is utilized. Details of this procedure will be presented later.

The encompassing concepts from the above investigations led to the basic underlying assumption used in this study: the characteristics of coasts result from interaction between terrestrial and marine factors. This statement can be considered as a first and general conceptual model, to be refined and dealt with later. The investigation follows the general guidelines suggested by Krumbein (Krumbein and Graybill, 1965, and Krumbein, 1969). In Krumbein's 1969 study he defined a conceptual model as "the mental pictures that we have about the phenomenon" (Krumbein, 1969, p. A-2). After this initial model is established, the next step is to formalize the conceptual model in quantitative terms by considering both theory and field data. Chorley and Kennedy (1971) developed model concepts within the context of General Systems Theory for the treatment of problems in physical geography.

A preliminary examination of the coast of South America intuitively indicates that a refinement of the initial general model is applicable to that coast. The model can be stated as follows: marine agents, mainly waves and tides, interacting with terrestrial elements of the coast (mainly geologic structure and lithology) can create along the shoreline response features such as coastal configuration, beaches, terraces, and cliffs and shoals. With the conceptual model in mind, the variables to be measured were decided upon and the statistical design was selected.

METHODS AND TECHNIQUES

At the present state of knowledge about the field of coastal geomorphology, consideration of all the interactions occurring among the variables in coastal environments is not possible. For this study specific methods and techniques are developed that are limited to relations among waves, tides, and selected geomorphologic features. These features include three geometric characteristics, Arc, Chord, and Crena (number of crenulations), and coastal landforms considered are Highland Coasts, Lowland Coasts, Shore Shoals, Rocky Terraces, and Beaches. All these features are defined later.

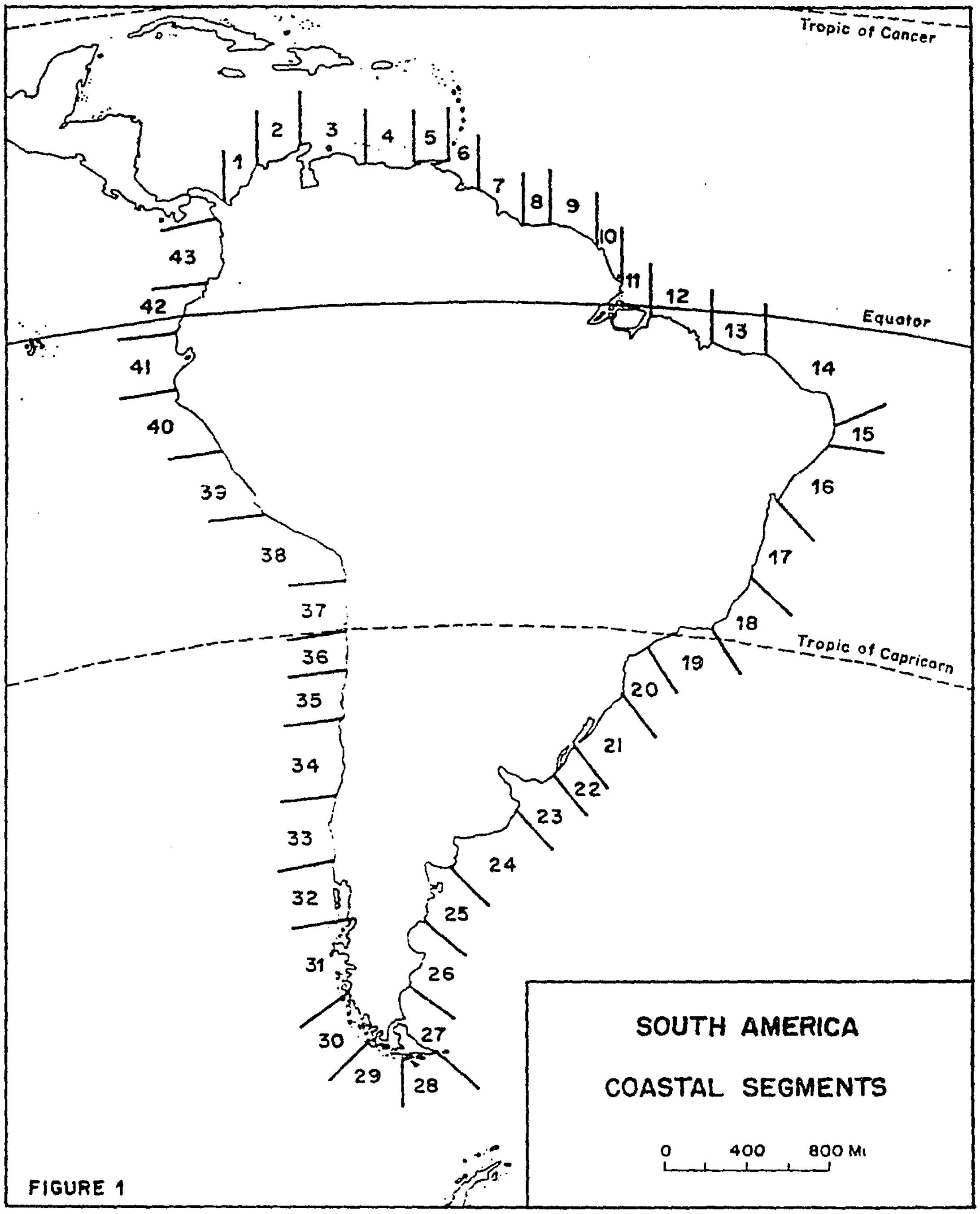
The study was limited to these features because the primary information had to be measured from maps, a fact which required that complete coverage be of the same scale and use relatively uniform symbology. Available maps were limited to 1:1,000,000 scale, and even these were not made by the same cartographic agencies and belong to several different editions. Sources for the maps are presented in the references, and their identification, for each analyzed coastal segment, is included in Appendix 1.

Analyses and computations of all the geomorphologic features, with the exception of crenulations, were based on their individual coastline lengths. Crenulations were expressed by their number along each coastal segment. Values of coastline lengths and crenulation counts, together with average values of tides and waves, make it possible to use multiple-regression techniques in analysis procedures. Numeric values of the measured features are presented in Appendix 2.

Upon selection of the map coverage at 1:1,000,000 scale, the coastline was divided into 43 segments of variable lengths (Fig. 1), ranging from 150.86 to 3,511.72 miles. These subdivisions constitute the experimental units on which the coastal features were measured (Appendix 1).

Lengths of coastal segments were determined by stretches of coasts which fall within the limits of a Marsden Square. Marsden Squares are geographic coordinates with 5 degree legs used by the U.S. Navy to summarize shipboard observations on waves, weather, and other sea conditions. Because waves constitute the primary marine process used in this study, Marsden Square limits provide the framework for quantifying the effects of sea and swell waves on coasts within the grid. The intersection of grid lines with the coast sets the limits for each of the coastal segments which comprise the experimental units used in this study.

Considerations were given to other systems for subdividing coastal segments, but, because wave climate provided process data at a resolution level correlatable within and between Marsden Squares, this system was adopted. Consequently, the perspective adopted in this work establishes,



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SOUTH AMERICA
COASTAL SEGMENTS
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FIGURE 1

first, the area upon which the marine energy processes are operating, and then measures and correlates terrestrial responses within the coastal segments, where wave energy is treated as uniform, and between units, where wave energy varies.

The main focus centers on spatial relationships between marine processes and responses, and through analysis significant factors interacting along coasts are identified. Considerations concerning time and evolutive development of coasts receive only limited treatment.

The South American coast was first divided into Marsden Square segments (Fig. 1). By overlaying the grid on the continent, 43 units were identified. The exact boundary between coastal segments may vary slightly because of the large scale of the base maps.

Information on marine processes around the South American coast is scarce, particularly detailed studies. The limited nature of the information restricted this study to continental scale treatment of process-response interactions.

Wave information came primarily from U.S. Navy oceanographic atlases. Wave data especially collected at Washington, D.C., for Russell (1969) was also used. For the scale of the study, sufficient information was available for each of the 43 coastal segments. In the above sources wave information (both swell and sea waves) is presented as wave roses showing percentage distribution of wave height classes for each 45 degree direction. Information on lengths of the waves is not available. Swell and sea waves are considered separately before being combined to obtain overall deepwater wave energy estimates.

To obtain an estimate of combined swell and sea wave energy, only the four rose directions facing the coastal segment are considered. For each month or season roses, for both swell and sea waves, a summation of the product for the midpoint of the wave-height classes times its respective frequency was calculated. This was done for each of the four rose directions, and the results for each month or season were summed and averaged to obtain a yearly energy input estimate. The formulas used are as follows:

Sea Waves

The average squared height of sea waves =

$$\frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} f_{ijk} \quad X_{ijk}^2}{\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} f_{ijk}} \text{, where}$$

m = number of seasons or number of months, depending on the arrangement of the data.

n = number of classes of heights (five classes were considered).

p = number of directions of wave approach (four directions).

f = percentage of occurrence of each wave height class at each direction at each season (or month).

X = sea wave height. The following height values were selected as representative of the classes:

(a) Moderate, 3 to 5 feet. Selected point: 4 feet.

(b) Rough, 5 to 8 feet. Selected point: 6.5 feet.

(c) Very rough, 8 to 12 feet. Selected point: 10 feet.

(d) High, waves equal to or greater than 12 feet, ordinarily less than 20 (Russell, 1969, p. 2). Selected point: 13 feet. This conservative estimated representative point is an attempt to compensate for the tendency of the wave observer to overestimate the heights of high seas.

(e) Confused, approximately 20 feet or more. Selected point: 20 feet. Because no indication of direction is given to this sea condition, the frequency values of this class were equally divided among the four considered directions.

The effects of sea waves of the classes slight (waves between 1 and 3 feet) and calm (waves less than 1 foot high) were considered negligible for the purposes of the present investigation.

In regard to the directions of approach of the waves, the procedure adopted was to divide every rose of directions from which data were being taken into two hemispheres. The direction of this dividing line was the trend of the coast (compass direction of Chord). Since the approach directions are 45 degrees from each other in the roses, each hemisphere contained four directions. Only the directions of the "maritime" hemisphere were considered.

Swell Waves

The average squared height of swell waves =

$$\frac{\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{k} f_{ijk} \quad X_{ijk}^2}{\sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{k} f_{ijk}}, \text{ where}$$

m = number of seasons or number of months, depending on the arrangement of the data.

n = number of classes of heights (four classes were considered).

p = number of directions of wave approach (four directions).

f = percentage of occurrence of each wave height class at each direction at each season (or month).

X = swell wave height. The following height values were selected as representative of the classes:

(a) Low, 1 to 6 feet. Selected point: 3.5 feet.

(b) Moderate, 6 to 12 feet. Selected point: 9 feet.

(c) High, waves equal to or greater than 12 feet, ordinarily less than 20 (Russell, 1969, p. 3). Selected point: 13 feet.

(d) Confused, approximately 20 feet or more. Selected point: 20 feet. Again, inasmuch as there was no indication of direction, the frequency values of this class were equally divided by the four considered directions.

The effects of the swell waves of the class less than 1 foot high were considered negligible for the purposes of the present investigation.

The above considerations regarding sea waves approach direction can be applied to the swell waves approach directions. Identical procedures were adopted in both cases.

The deepwater wave energy indicator (Wave) is based on the knowledge of wave heights offshore from the coastal segments and, as stated before, is the sum of the average squared height of sea waves and the average squared height of swell waves. The implication is that the effects of these two types of waves on coastline morphology are considered in combination and cannot be treated separately at the scale of this investigation.

The index Wave is compared with the expression for wave energy per unit area of water surface presented by Wiegel (1964, p. 13):

$$E_s = \frac{\gamma H^2}{8}$$

where γ, the unit weight of water, is considered a constant. It is evident that in both expressions the essential variable is the height of the waves. Thus, the index Wave, the sum of the average squared heights of sea and swell waves, can be proposed as an index of the wave energy at deep water. It is not a complete measure of the wave energy, but it is an indicator of the variation in wave energy at deep water and consequently can be used in regression analyses.

Inasmuch as this investigation concerns coastal features, the index Wave, which represents a deepwater wave energy condition, had to be modified in such a manner as to account for the wave energy effects at zero depth. This modification, at the scale of this study, is represented by the multiplication of the values of the index Wave by a specially devised index of wave energy dispersion, $\sqrt{\text{Chord/Arc}}$.

The ratio Arc/Chord (that is, the square of the inverse of the index of dispersion mentioned above) expresses for each coastline segment the amount of its departure from the straight line because Arc is the coastline length of the segment and Chord is the straight line connecting the extremities of Arc (Fig. 2). It is by itself a first approximation to the shape of the coastline.

On the other hand, a similar ratio is commonly used in the literature (Bretschneider and Reid, 1954, p. 1; Wiegel, 1964, p. 156) as a refraction coefficient for waves in shoaling water. This coefficient is $\sqrt{b_o/b}$, where b_o is the length of a wave crest between two orthogonals at deep water and b is the length of wave crest between the same orthogonals at any lesser depth.

The similarity becomes clear if Chord is considered equivalent to b_o--that is, the length of a hypothetical wave crest along which the deepwater wave energy is distributed--

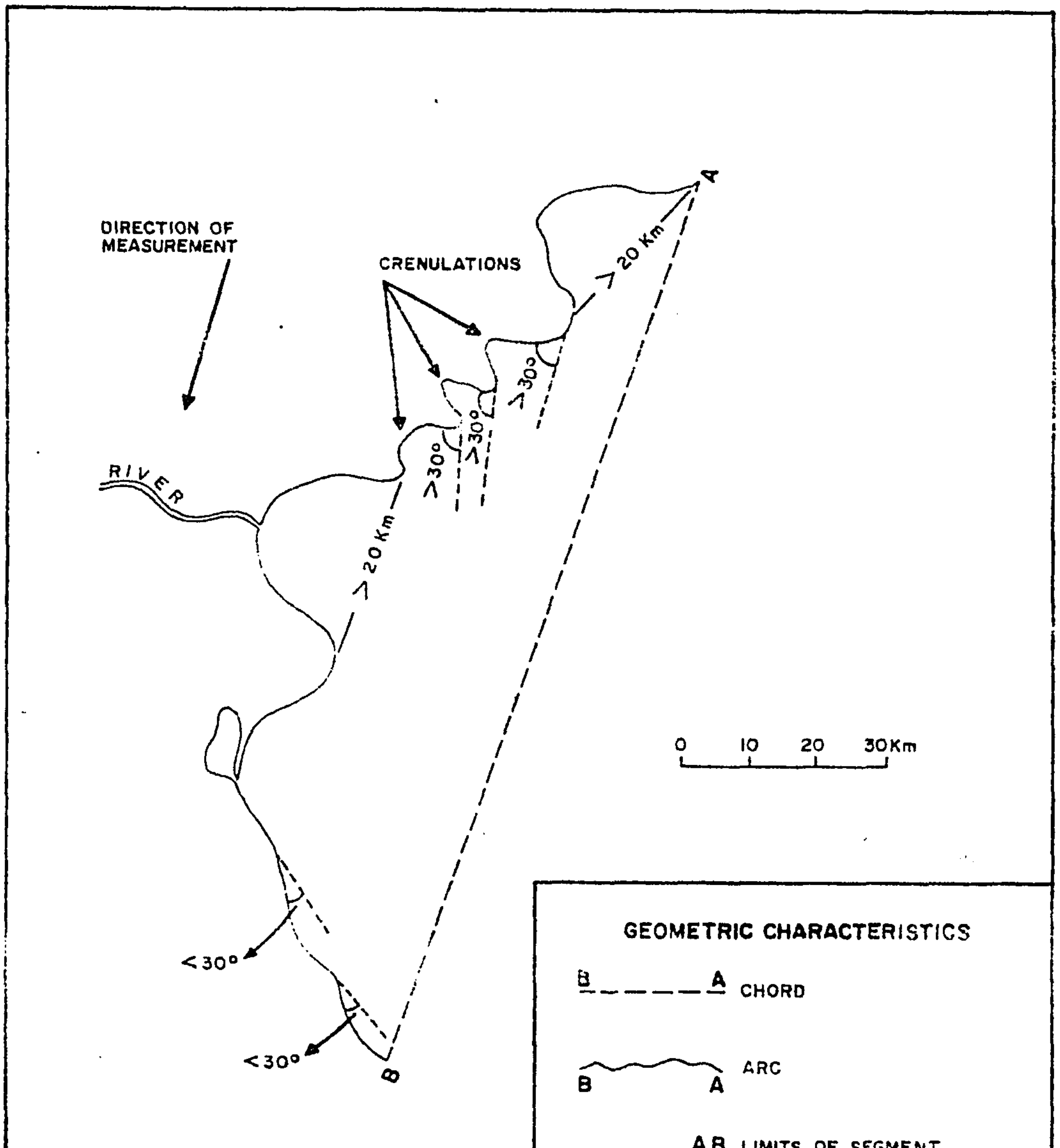
DIRECTION OF
MEASUREMENT
CRENULATIONS
RIVER
> 20 Km
> 20 Km
> 30°
> 30°
> 30°
< 30°
< 30°
A
B
0 10 20 30Km
GEOMETRIC CHARACTERISTICS
B A CHORD
B A ARC
AB LIMITS OF SEGMENT

FIGURE 2

and Arc is considered equivalent to b, the length of the same hypothetical wave crest at zero depth, which is the final line along which the wave energy is dispersed, i.e., the coastline. Then $\sqrt{b_o/b} = \sqrt{Chord/Arc}$. Consequently, at the scale of the present investigation, the index $\sqrt{Chord/Arc}$ is considered representative of the wave energy dispersion along the length of the coastline segments being studied. It is dependent, as is its counterpart $\sqrt{b_o/b}$, "upon the configuration of the bottom, the initial orientation of the waves in deep water, and the wave period" (Bretschneider and Reid, 1954, p. 1).

The above index of wave energy dispersion modifies through multiplication the deepwater wave energy values of the index Wave, as mentioned before, and this interacting combination, that is, the composite index Wave times $\sqrt{Chord/Arc}$, is included as a single independent variable in the regression analyses of this study (Table 1 of Appendix 3). The above composite index represents, at the scale of the present investigation, the wave energy reaching the coastline of each segment.

Tidal information was largely drawn from Russell (1969). Both mean and spring tide ranges were initially considered, but because both showed nearly identical variation along the coast spring tide ranges were used. Midpoint values for each of the spring tide range classes as presented by Russell were used for each coastal segment. As an example, if a spring tide range is shown as varying between 7.2 and 7.8 feet, as is the case of the French Guyana coast (Fig. 1, segment 9), the midpoint was determined as 7.5 feet, and this value was considered representative for the entire segment.

The inclusion of tidal range as one of the independent variables of regression schemes is justified by the preliminary assumption that the variation in water level brought by the tides would bring disturbances to the activity of the other marine agent being analyzed, namely, waves.

Probably the most significant effects of tidal ranges in coastal morphology are associated with wave activity. The larger the variation in water level during a given period, the smaller the permanency of the wave system at each particular plane (Davies, 1964, p. 137), and, consequently, the less work can be executed by the waves at that plane. With large tidal ranges the tendency of the coastline is to present poor sorting of shore clastics (King, 1959, p. 229). Tideless shorelines show more clearly the work of waves, usually under the form of a better sorted material and presence of submersed bars related to the location of breakers (King, 1959, pp. 231, 232, 333).

Coastal morphological considerations included Beaches, Highland and Lowland Coasts, Shore Shoals, and Rocky Terraces. In each coastal segment these morphological response features were identified and measured in reference to coastline length. Inherent in morphological considerations are geometric elements of coastal configuration. To quantify configuration the following geometric characteristics were considered (Fig. 2):

<u>Arc</u>. Length of the coastline between the adopted limits of the segments of the South American coastline.

<u>Chord</u>. Straight-line distance between the adopted limits of the coastline segment.

<u>Crenulations</u>. Sum of the small notches or indentations occurring along the coastline segment. One crenulation is computed as a change in direction of more than 30 degrees in the Arc, landward, counted in the same sense of the measurement of the coastal landforms (clockwise around the South American coast). Only small indentations are considered, i.e., those with less than 12.5 miles (20 km) of Chord (see Fig. 2). Indentations with Chords larger than 12.5 miles (20 km) are considered as being represented in the ratio Arc/Chord or in the index $\sqrt{Chord/Arc}$ and thus are not computed as crenulations. Lagoon inlets and river mouths are not considered crenulations.

The geometric characteristic Crena represents the occurrence of small indentations along the coastline (Fig. 2). These coastal features are considered an indicator of geologic influences such as the presence of small-scale jointing, faulting, and folding, and local lithological variations. Strahler (1957), accepting ideas of Smith (1950), adopts similar indentations of contour lines as representative of the presence of small streams in the upper portions of river basins. Mousinho de Meis and Xavier da Silva (1968) give accounts of the close relationship between the mentioned geologic factors, especially jointing, and the topographic details associated with crystalline rock. Because the present zero-meter coastal contour line is the limit of an overall submerged coast, its abrupt jaggings (as defined above) can be considered indicative of detailed geologic influences.

Among the coastal landforms uniformly identified on maps, the most important are beaches. They are represented in this study by the ratio Beaches/Arc, which was selected as the dependent variable in the multiple-regression screening schemes.

Beaches are relatively long-term equilibrium features (Hoyle and King, 1958; Tanner, 1958). They can be considered response features that directly incorporate the activity of waves eroding, transporting, and depositing clastics, the action of tides disturbing the sorting effected by waves, the arrival of fine-grained alluvial sediments, and the history and lithology of the coast, all of which are responsible for the generation of shore clastics.

Identification of beaches from maps was accomplished by use of criteria which would provide positive identification of the feature. These criteria, which were not mutually exclusive, are (a) statement on the maps such as beach, playa, praia, etc.; (b) presence of inundated lowlands landward from the beach; (c) presence of a road or trail landward from the immediate shoreline if the 100-meter contour was more than 2 km from the shore; (d) characteristic shapes of arcuate beach shorelines, barrier beaches, barrier islands, and spits (Lewis, 1938; Hoyle and King, 1958; Davies, 1959).

Highland and Lowland Coasts comprise the second and third categories of coastal landforms, and along each coastline segment these types were measured. If the 100-meter contour line occurred 2 km or more from the shoreline, this coastal extent was considered a Lowland Coast. If the 100-meter contour line occurred less than 2 km from the shoreline, the coast was classed as Highland. The sum of Highland and Lowland coastal lengths was expected to be equal to Arc.

Units of the metric system were used in the recognition of some of the coastal features. This resulted from the use of maps edited under that system, basically. The scale of the maps used is 1:1,000,000 (a millimeter to the kilometer) and, even more significantly, the topographic contours have 100-meter intervals.

The occurrence of Highland Coast features indicates the presence of considerable topographic irregularities near or at the shore. Such occurrence relates to the geologic history of the area, in which such events as mountain uplift (Andes), large-scale faulting (southeastern Brazil), and Quaternary glaciation (southern Chile) occurred and have had an important role in the evolution of the present-day characteristics of the coastline.

Along Lowland Coasts the same geologic influences may also be present, but at the scale of the map they cannot be directly recognized. Topographic features occurring between zero and 100 meters obviously could not be clearly recognized from maps which used the 100-meter contour intervals as their smallest altimetric unit. This limitation concerning Lowland Coasts, however, does not apply to Highland Coasts, which by definition directly relate to the occurrence of high relief at the coast.

Shore Shoals and Rocky Terraces constitute the two remaining morphologic features. Shore Shoals are deposits of mud and/or sand found in the nearshore zone, and their occurrence along a coastal segment is considered indicative of at least two types of influences, which are not mutually exclusive. These are the presence of great tidal ranges and large sediment supplies from discharges of major rivers (Amazon, Orinoco, Sao Francisco, and others). Rocky Terraces are identified as rocks on the maps covering the Patagonian coast, where they are conspicuous. These landforms occur in a narrow band near and along the shoreline and are believed to be ancient elevated shore features

(Auer, 1959; Feruglio, 1950). Because Rocky Terraces were clearly identifiable on the maps covering the Patagonian coast of Argentina and as such were consistent with the basic criterion for selection of features in this study, they were included as one of the variables, although their importance on a continental scale was expected to be very low.

In limited situations, such as indentations along the Patagonian coast and the Amazon River mouth, measurement of Shore Shoal and Rocky Terrace coastal lengths presented additional measuring problems. Their form does not strictly follow the configuration of the coastline, and therefore their greatest nearshore length was considered representative of their occurrence.

Islands are conspicuous features along many segments of the South American coast. They greatly complicate quantitative treatment because of the complexity of their relations with propagation of waves. In this study the effects of islands on waves is considered in the same manner as shoaling effects along the coast. Consequently, for islands having only a narrow channel separating them from the mainland, they were included as part of the coastline length. If the islands lay long distances offshore, they were not considered.

Reefs were not considered in the study because they were not uniformly identified on all the maps in which they are recognized.

GEOMORPHOLOGIC INTERPRETATIONS OF SELECTED SEGMENTS

The 43 coastal segments were measured and analyzed for both marine energy and coastal morphologic features. Analysis was based on multiple-regression techniques, which will be discussed in the following section. The variables used in the analysis can be used to describe quantitatively the major geomorphic features. Eight coastal segments were selected as representative of contrasting environments in terms of terrestrial controls and marine forces. The eight coastal segments selected were mapped; they comprise the basic units for discussion in this section (Figs. 3-10). They are represented in Figure 1 by numbers 2, 10, 15, 19, 24, 30, 37, and 42. Figures 3-10 are reduced and simplified versions of the 1:1,000,000 scale maps used for the actual measurements.

In the maps the geometric characteristics Arc, Chord, and Crenulations and the coastline lengths of the landforms Beaches, Highland and Lowland Coasts, Shore Shoals, and Rocky Terraces were measured in each coastal segment through the use of a CALMA 300 digitizer. This instrument facilitated precision in the measurements. A systematic error check, based on the expected value of one for the ratio between the length of the coastal segment (Arc) and the sum of Highland Coasts plus Lowland Coasts, did not indicate differences greater than 3 percent in any case. The lengths of the coastal features were obtained directly in miles by means of an IBM 360 computer program designed to process the CALMA 300 data.

The information on surface geology such as alluvium, hard rock, etc., is only approximate. The basic considerations of the present work centered on the shoreline, and thus no great accuracy was sought on the delimitations between different lithologies. The basic source of geologic information for the maps was the "Mapa Geologico da America do Sul" - 1:5,000,000 - Lamego (1964). Some information was also obtained from Jenks (1956).

The data on tides and waves come from Russell (1969) and the U.S. Navy oceanographic atlases. These sources provided uniform data which were applied to South American coasts. Calculations concerning waves and tides, combinations of numeric values of geomorphic features (ratios and indexes), and other computations were made through the use of a Wang 700 programmable electronic desk calculator.

<u>Segment 2 - Punta Balilla to Cabo de la Vela</u>

Segment 2 (Fig. 3) is part of a large sector of the Caribbean South American coast, where the structural trends of the Andean Cordillera provide the basic coastal framework. Northern branches of the Andes extend to the sea and form the cradle for the Magdalena River valley, located

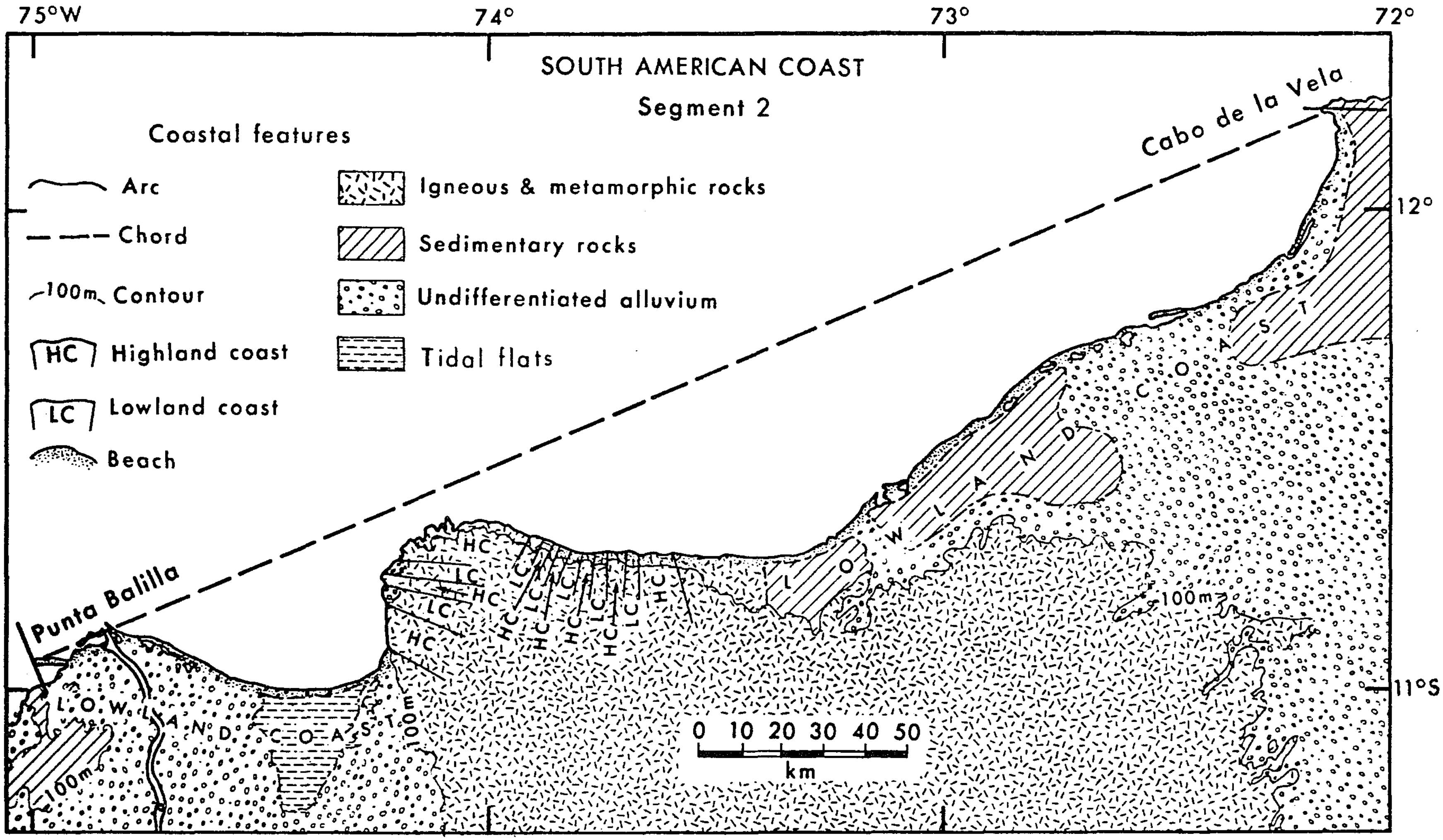

Figure 3. Typical sector of the Caribbean coast.

on the left margin of Figure 3.

The specific coastline configuration of this segment clearly indicates the presence of one strongly defined geologic structure in its middle western part. This coastal projection is part of the crystalline Sierra Nevada de Santa Marta, identified as a structure separated from the Andean system by Olsson, in Jenks (1956, p. 325). The projection forms a conspicuous highland coast where resistant rocks are sculptured by mechanical erosion. Waves are working only the details of this stretch of coast; its main character is provided by terrestrial influences, particularly the resistant lithology and the local geologic structure.

The western part of this coastal segment is dominated by depositional forms. Sediments transported by the Magdalena River are deposited along this stretch of coast, where extensive beaches isolate large tidal flats and lagoons from the sea.

The eastern portion is dominated by sedimentary deposits. Large beaches reflect the depositional activity of waves. This section is a low coast where no large rivers empty into the sea and small tidal lagoons and flats lie landward behind barrier beaches. This situation indicates that less sand is available in comparison to the western coast. The beach sands were likely eroded from the shelf during the last rise of sea level and had their ultimate origin in reworking of the sedimentary rocks.

The coastline length of this segment is 259.08 miles (Arc). Tidal ranges are small, and in general spring tide range is only 1.5 feet (Russell, 1969). This segment is exposed to swell and sea waves of the Caribbean Sea, which have a dominant northeast direction. The value of deepwater wave energy (the index Wave) offshore is 105.25. This value is compared to a maximum of 188.65 for southern Chile and a minimum of 37.24 for the northwestern Pacific coast of Colombia. Wave energy reaches the coastline modified by energy dispersion factors such as bottom friction and refraction. The coastline has a relatively small departure from straightness, as indicated by the ratio Arc/Chord = 1.23. The fact that deepwater energy is not highly dispersed while moving shoreward is indicated by the value of 0.90 for the index of wave energy dispersion $\sqrt{\text{Chord/Arc}}$. The abundance of beaches along this coastline (ratio Beaches/Arc = 208.56/259.08) seems to be directly related to wave activity. Although terrestrial factors dominate part of the central coast, the above-mentioned small departure from straightness associated with few crenulations (23) indicates that the configuration of this coast can be explained mainly by marine energy factors, in this case waves, inasmuch as the long beach arcs contribute to the regularity of the coastline and the small tidal ranges do not play a significant role.

Segment 10 - Pointe Behague to Cabo Norte

The coastal segment from Pointe Behague to Cabo Norte (Fig. 4) is typical of the muddy, low, and mangrove-rich Guyana coast. Deposition from the Amazon River sediment load and high-range tides (19 feet of spring tide range) have a clear imprint along this entire coast. Reclus (1897) gives a general account of the Guyana coast, and Vann (1959) discusses the occurrence of beaches and the effects of tides and currents.

The coastline length of segment 10 is 325.86 miles. It is a fairly straight coastline having an abrupt change of direction in its northern part, where crystalline rock outliers projecting from the Guyana Massif comprise a series of flat-topped hills which reach the proximity of the coast. The segment's ratio Arc/Chord amounts to 1.46, and few crenulations (23) occur at the coastline. Tidal flats and shore shoals dominate the coast. Many rivers incur upon this coast, coming from a general westerly direction. Their discharges are checked when they reach the tidal flat areas, and the waters are spread over the coastal lowlands, which are also supplied with brackish water during high tides. Abundant mangrove swamp and marsh grasses and sedges thrive on that wet-ground environment.

The wave energy at deep water offshore from this segment is relatively low (the index Wave = 71.56), and swells and seas come predominantly from the northeast and the east. This wave energy reaches the coastline modified

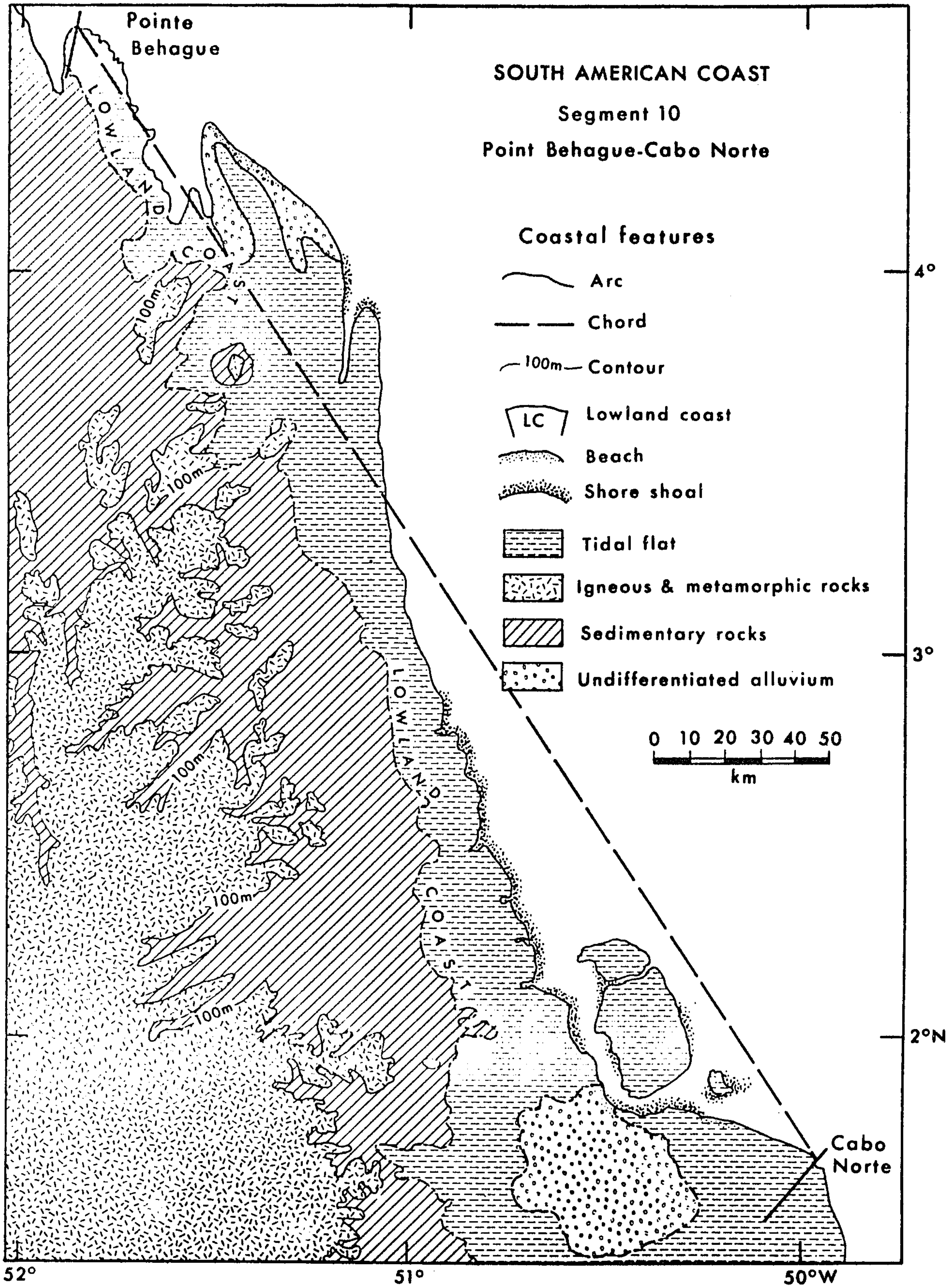

Figure 4. The Brazilian portion of the Guyana coast.

by an index of energy dispersion ($\sqrt{\text{Chord/Arc}}$) of 0.83 and thus is reduced to 59.39, the value of the composite index Wave $\cdot$ $\sqrt{\text{Chord/Arc}}$. Already areally dispersed, the wave energy is spent along a fairly large part of the shoreface zone. Because the high tidal ranges and abundant sediments occur in a shallow shore, the energy of the waves cannot be concentrated on a narrow vertical section of the coast. Wave action has to move constantly up or down across the intertidal zone. As a result, only a small amount of sorting of the coarser clastics is done at any one level, and the shoreface remains constantly composed of fine-grained shoals.

In conclusion, it can be stated that coastal segment 10 has practically no beaches, its main characteristic being the presence of shore shoals (the ratio Shore Shoals/ Arc is 111.54/241.49). This situation is induced by the occurrence of high-range tides in an area of abundant sediment supply.

Segment 15 - Cabo de Sao Roque to Olinda

Segment 15 is situated in the northern part of the eastern facade of South America. Descriptions of this coast can be found in Lacerda de Melo (1956) and Andrade (1967). Segment 15 is exposed to the dominantly southeast and east sea and swell waves of the South Atlantic Ocean. In this bulge of northeastern Brazil the coast is practically straight (index Arc/Chord = 1.10), and the wave energy at deep water (index Wave = 80.48) reaches the coast affected slightly by dispersion (index of wave energy dispersion = 0.96). The small number of crenulations (19) indicates a general absence of hard rocks along the coastline. The waves actively attack the headlands, which are often composed of sedimentary rocks, and form abundant beaches (the ratio Beaches/Arc = 125.21/191.73). Many tidal flats are sealed off from the sea by these beaches.

Tides are of medium range along this coastal segment (6.65 feet for the spring tide range), in which mangrove swamps and some shore shoals are found. These features can be attributed to the action of tidal currents moving in and out of the mouths of water courses in the coastal plain. As can be seen in Figure 5, they occur mostly at or near the mouths of rivers and other narrow indentations of the coast.

In summary, this coast is dominated by marine processes, mainly by the action of waves. Evidence of terrestrial controlling factors is the continental bulge itself, which has a crystalline core. The occurring sedimentary rocks, which are mostly poorly consolidated sands, silts, and gravels of Tertiary and Early Quaternary age (Bigarella and Andrade, 1965), are fashioned by the waves through the destruction of headlands and the building of beaches into the nonindented and straight coastline configuration of the segment.

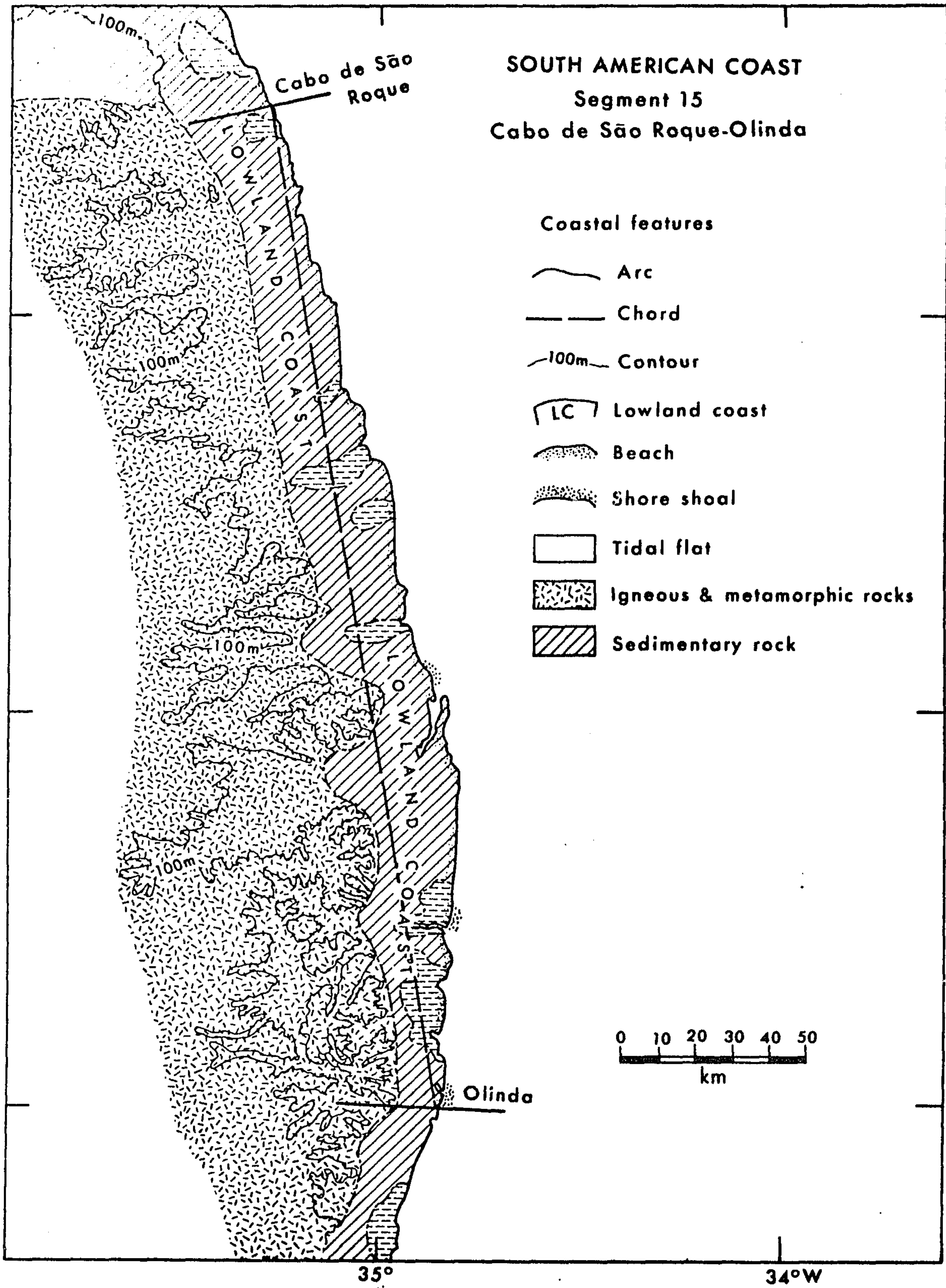

Figure 5. Typical section of the northeastern Brazilian coast.

Segment 19 - Arraial do Cabo to Ponta Itacurussa

Coastal segment 19 (Fig. 6) is typical of that part of South America where the pre-Cambrian crystalline rocks of the Brazilian Plateau reach the shore. The association of the fairly high value of the index Arc/Chord (1.81) with the large number of crenulations (172) indicates the presence of terrestrial controls in the coast, such as geologic structure and hard rocks.

Sea and swell waves from seasonally variable directions incur upon this coastline. The deepwater wave energy (index Wave = 96.71) is greatly affected by dispersion (index of wave energy dispersion = 0.74) and becomes reduced, at the shoreline, to 71.56. Although the present-day sediment supply to this coast is scarce, a relatively large amount of beach occurs in this coast (ratio Beaches/Arc = 316.12/728.90). The beach sands (as may have occurred along other coastal segments) probably had their immediate origin in the activity of waves scraping the continental shelf floor during the last sea level rise, Their remote origin may be connected to the abundant subaerial generation of clastics during Quaternary low stands of sea level in this area. During those interglacial times semiarid geomorphologic conditions prevailed in that mountainous, high-energy southeastern region of Brazil (Bigarella _et al_., 1969; Damuth and Fairbridge, 1968).

Tides are small along this segment (3.6 feet for the spring tide range). Shore shoals are absent, and tidal

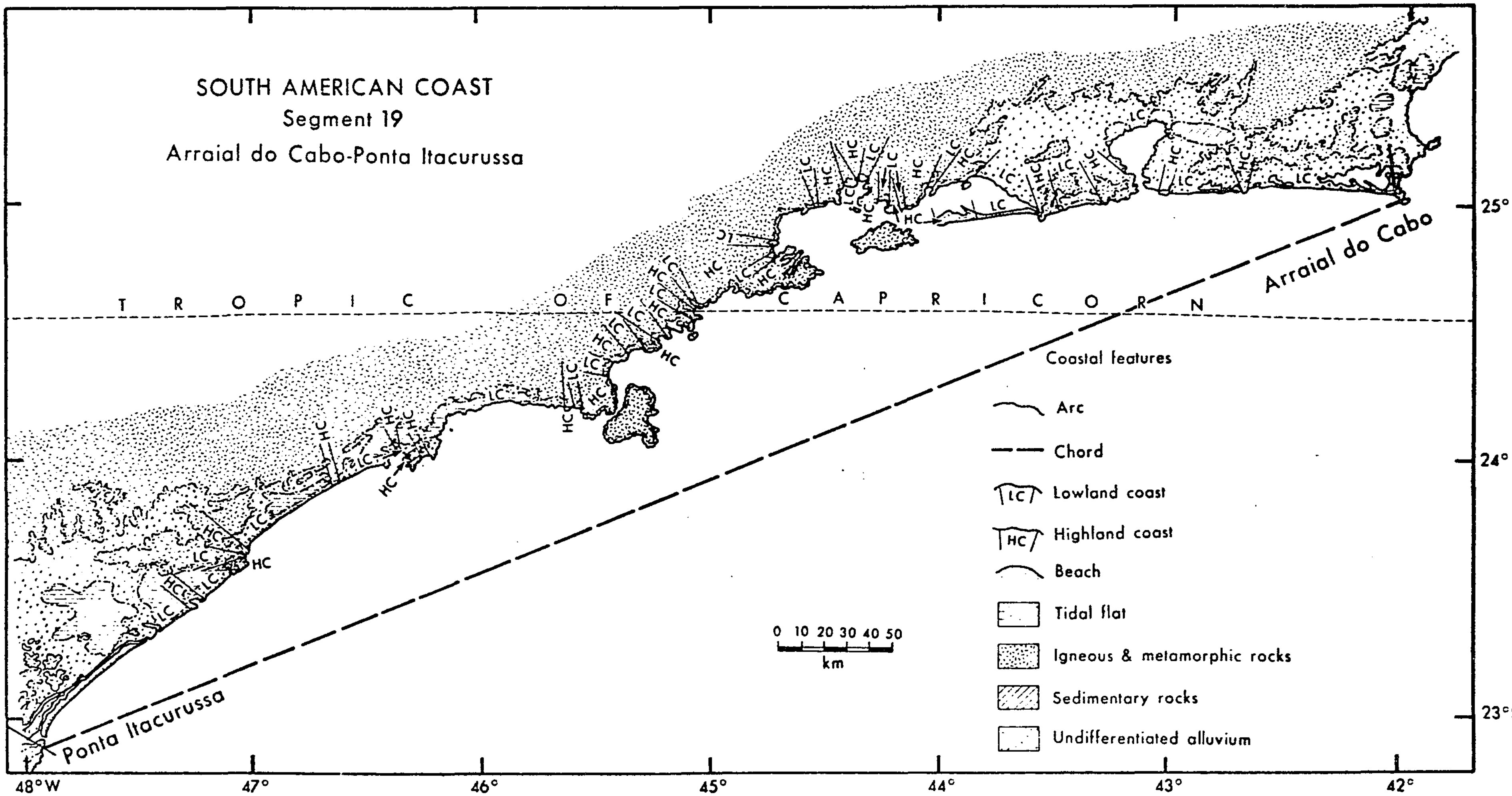

Figure 6. Coast of the crystalline highlands of southeastern Brazil.

flats are related to lowlands separated from the open sea by long beach ridges.

In conclusion, it can be stated that this segment clearly shows the interplay between marine and continental shoreline-forming factors. Beaches are common along the coastline, but their length is always determined by the occurrence of hard-rock headlands. Waves pound on the abundant highland coasts but are not very efficient in generating clastics by erosion. The hard-rock headlands do not show signs of significant recession (wave-built sea cliffs, caves, and platforms). The waves disperse their energy along the irregular coastline and have already established an unstable equilibrium, expressed by the long, arcuate beach ridges connecting the rocky headlands.

Geomorphologic, oceanographic, and geologic papers of interest about this area - the most developed zone of Brazil - are very numerous in the literature (this is not true of most of the other analyzed segments). Among these are Ruellan, 1944; Guerra, 1965; Maio, 1958; Dansereau, 1947; Ab' Saber, 1955; Besnard, 1950; Sadowski, 1954; Bigarella _et al_., 1969; Moreira da Silva, 1952; Tricart, 1959; Silveira, 1952; and Lamego, 1948. Papers concerning the coast south of this segment are also abundant (Salamuni and Bigarella, 1962; Bigarella, 1965; Bigarella and Freire, 1960; and Butler, 1970). Investigations concerning beaches, in particular, can be found in Bigarella _et al_., 1966; Bigarella and Popp, 1966; Bigarella, 1965; and Delaney, 1962.

Segment 24 - Faro Medanos to Punta Rosa

Quaternary undifferentiated alluvium dominates the low-lying coast of segment 24 (Fig. 7), which is situated from just south of the La Plata estuary to the northern part of the Patagonian Plateau. A general account of the type of environment in this area, particularly its stratigraphy, can be found in Garcia and Garcia (1964). Beaches are mostly found along the northern part of this coastal segment (ratio Beaches/Arc = 138.95/662.25). In the southern part, near all the main indentations of the coastline, shore shoals characterize the coastal environment.

Along this entire coast are frequently found tidal flats and lagoons occurring landward from the shoreline. High tidal ranges are typical (18 feet for the spring tide range) and, as noted before in relation to segment 10, the tide interacts with wave breakers, causing them to move constantly across the extensive intertidal zone. Abundance of fine clastics in these conditions results in an accumulation of mud and silt near the indentations of the coast, giving origin to the shore shoals which characterize the southern part of the coastal segment (ratio Shore Shoals/Arc = 330.13/662.25).

The deepwater wave energy is high for this segment (120.48). Swells and seas present variability in direction, fairly high waves coming from the south. Their energy is well dispersed (index of dispersion = 0.79). Deposition

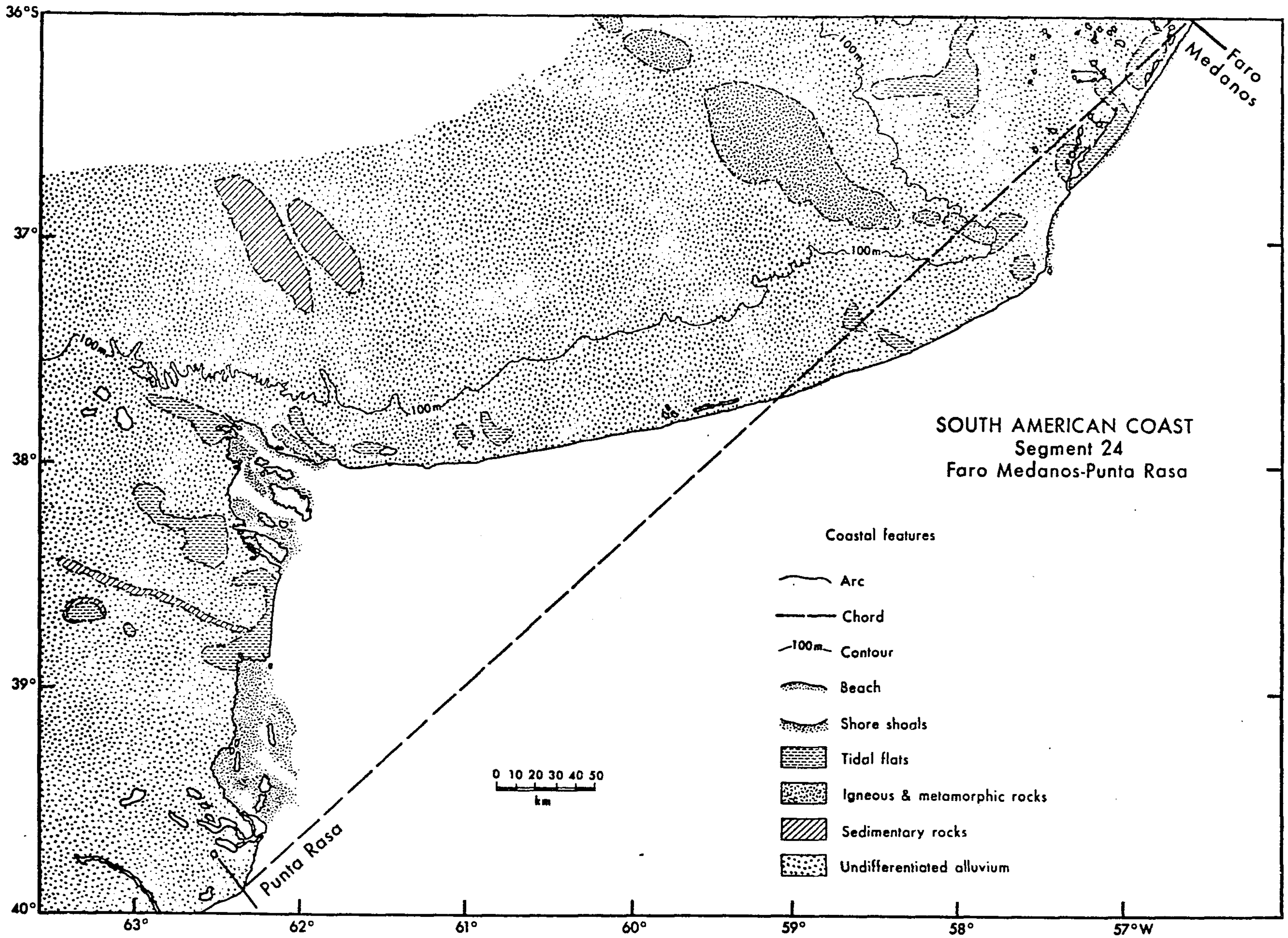

Figure 7. Argentinian coast just south of the La Plata estuary.

of sand is concentrated on the coastline of the northern seaward-bulging part of this coastal segment. An interesting analysis of this northern area can be found in Willis (1912). The presence of a roughly east-west hard-rock core in this bulge is a measure of the geologic structural control on the overall configuration of this coastline segment. Ewing et al. (1963, p. 288) delineate the geologic structure controlling the general configuration of this coast, which exhibits some departure from straightness (index Arc/Chord = 1.60). The relatively small number of crenulations (63) indicates, however, that lithologic factors are not acting directly at the shoreline.

This segment has a twofold character. Along its northern part, waves are able to build a significant amount of beach along this coastline, which, under remote structural control, clearly faces waves coming from the south and southeast. On the southern part shore shoals dominate the coastline, probably in response to a lower degree of exposure to wave action and because the effects of high-range tides are stronger along confinements of seawater. Such is the case of the shoals found at the rather pronounced indentations of the coastline which characterize the southern part of this coastal segment.

Segment 30 - Cabo Deseado to Cabo Hawksworth

Coastal segment 30 (Fig. 8) is dominated by its geologic structure and by the fact that this area suffered intensive glaciation during the Quaternary. Rocks of different

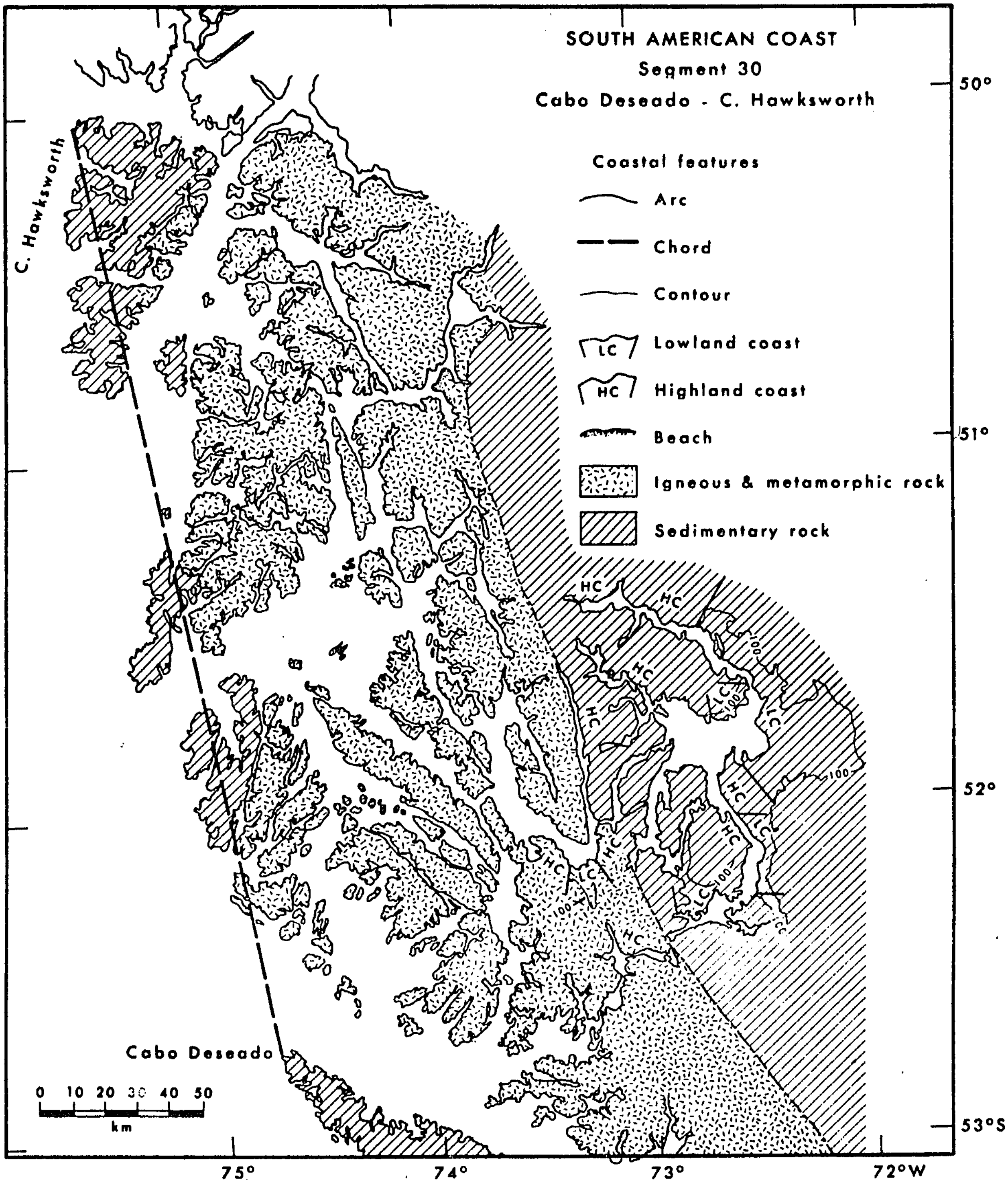

Figure 8. Mountainous and glaciated coast of southern Chile.

types show the same general topography of vertical cliffs and drowned and steep valleys (fiords). A rugged terrain is certainly a major characteristic of this coast. Both the ratio Arc/Chord (11.15) and the number of crenulations (600) are very high, indicating a coastline controlled by geologic structure and resistant lithology, although in this case the climate and geology history were important in a remote sense.

Strong swell and sea waves having directions varying between the northwest and the south incur upon this coastal segment. Wave energy at deep water is high (188.65, the highest index Wave value among the 43 segments of the South American coast). But the wave energy dispersion index indicates a large loss of energy for the waves refracting and reflecting along this highly indented coast ($\sqrt{\text{Chord/Arc}}$ = 0.30). Beaches and tidal flats are practically absent along this shoreline, which is almost entirely composed of highland coasts (ratio Beaches/Arc = 18.04/2106.36 and ratio Highland Coasts/Arc = 2018.54/ 2106.36).

Tides are relatively small along this segment (5.9 feet for the spring tide range). No shore shoals were registered at the scale used in the present investigation. The characteristics of the segment are the result of terrestrial controls, i.e., a reflection of its geologic structure and lithology, upon which a sequence of geomorphologic events related to Quaternary glaciations left a definite and typical imprint. Thomas (1949) gives an account of the basic traits of the geologic structure of this area. Bruggen (1950) presents an encompassing treatment of the geology of Chile in which much information about the characteristics of this coast is given.

Segment 37 - 20 to 24 Degrees South

The western coast of South America, from central Peru southward (Fig. 9) is dominated by the geologic structure of the Andean Cordillera. In this segment such influence is clearly displayed by the ratio of highland coasts to the total coastline length (331.54/351.34).

The geology and physiography of this coastal area are described in Harrington (1961). More information about this coast can be found in Rich (1942) and Munoz Cristi (in Jenks, 1956). Fuenzalida et al. (1965) present extensive considerations about Quaternary sea level variations along the Chilean coast. Geologic and physiographic data also can be found in Bruggen (1950).

A small amount of wave energy is registered at deep water for this segment (Wave = 75.51). It comes from the sea and swell waves of the southeastern Pacific, which have as dominant directions southwest and south. This energy suffers a relatively low dispersion (dispersion index = 0.89). Sands are deposited on pocket beaches and where the structure creates a coastline protuberance, as in the peninsula occurring in the southern part of the segment. Waves are spending their energy directly against

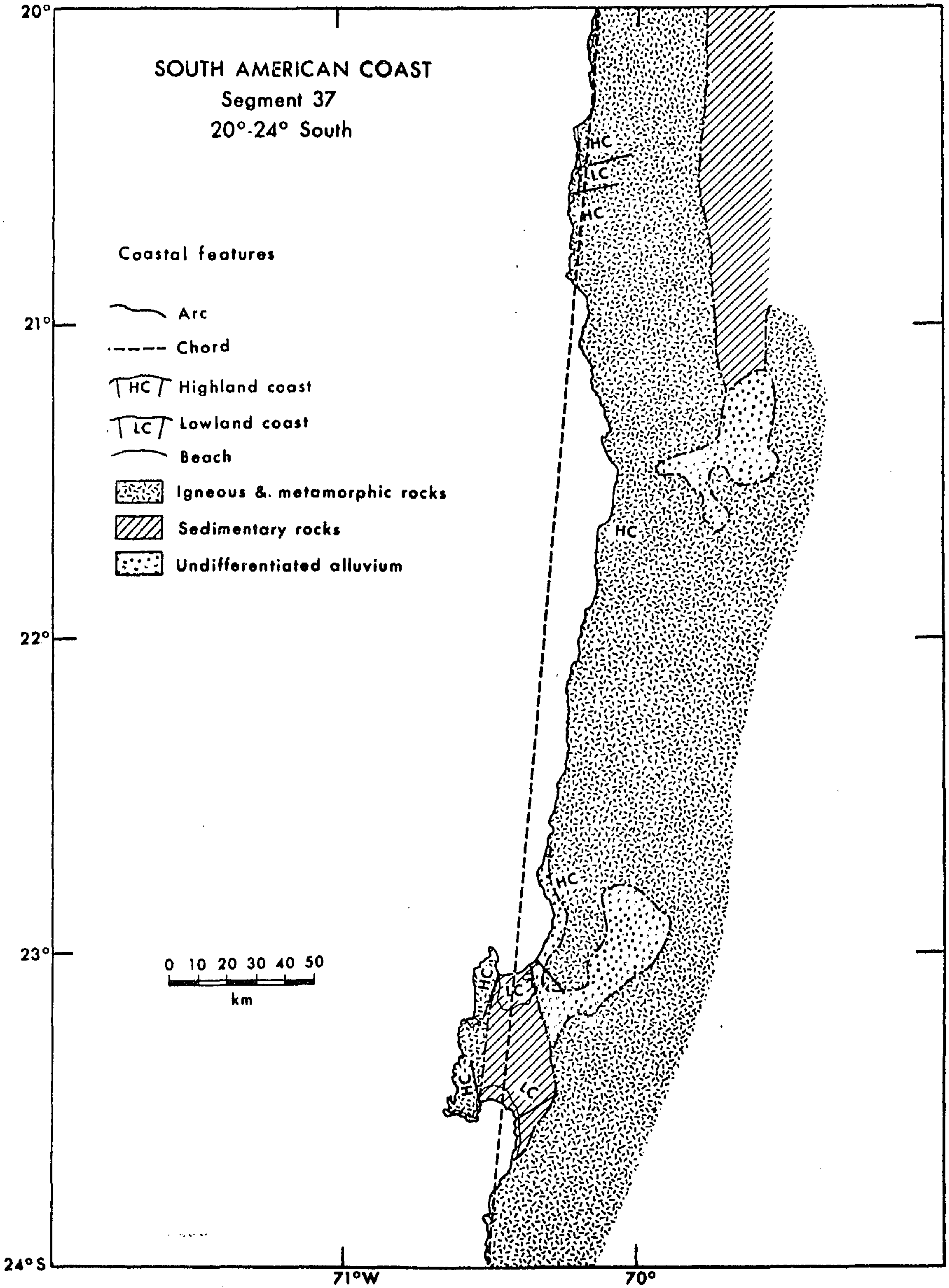

Figure 9. Structure-dominated coast of northern Chile.

the igneous and metamorphic rocks composing the highland coasts which are predominant along this coastal segment (number of crenulations = 96).

Tidal ranges are not high (5 feet for the spring tide range), and no shore shoals or tidal flats were registered at the scale of the present work.

It can thus be concluded that the geologic structure of this coastal segment, in addition to controlling the coastline configuration, conditions the use of the available wave energy in the erosion of highlands and in the localized deposition of the sands on the small beaches found along the segment coastline.

Segment 42 - Cabo S. Lorenzo to I. de Gallo

Segment 42 (Fig. 10) is situated mainly on the Equadorian coast facing the Central Pacific Ocean area, the northern fifth of it advancing into Colombia. Detailed geographic analysis of most of this coast is contained in West (1957). A less elaborate description is found in Murphy (1939).

Pacific sea and swell waves predominantly from the southwest are responsible for a deepwater wave energy index (Wave) of 61.56. This energy is dispersed along a coast having a variable general configuration, which causes it to have a fairly high ratio of Arc/Chord of 1.78, which is indicative of some geologic structural control, and a wave energy dispersion index of 0.75. The low number of crenulations (52) and the low ratio of Highland Coasts/Arc

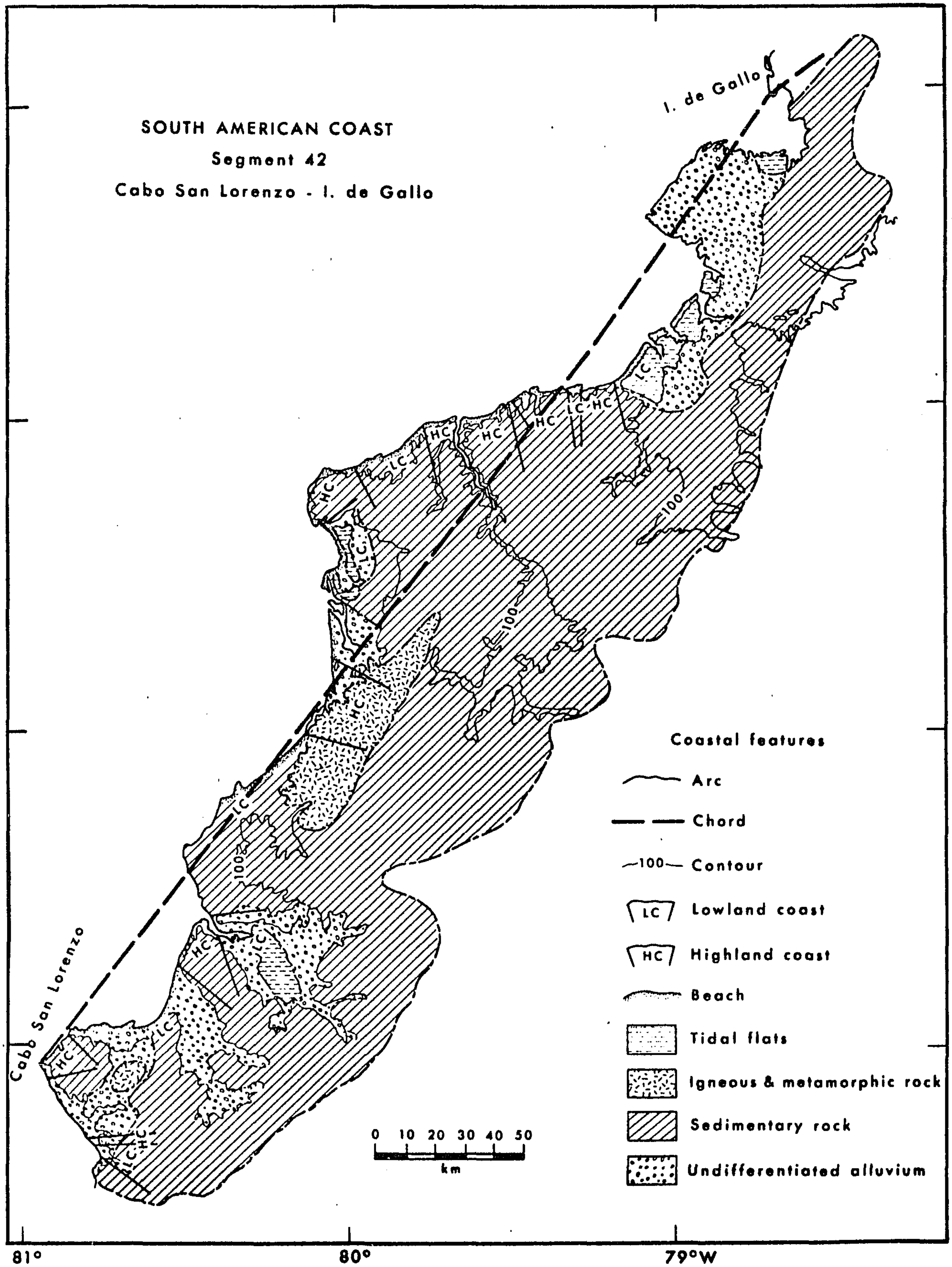

Figure 10. North Ecuadorian and south Colombian coast facing the Central Pacific Ocean.

(99.59/468.46) are related to the presence of sedimentary rocks along most of the coastline. Beaches are frequent, and in many instances they isolate tidal flats landward.

Tidal ranges are relatively large (9 feet for the spring tide range) and tidal flats extend landward in response to the action of tidal currents along deep indentations of the coastline.

In all, this coastal segment seems to be responding to the activity of waves, which erode the sedimentary rocks and build beaches (ratio Beaches/Arc = 171.83/468.46). Consequently, waves are producing changes in the coastal configuration, but this coastline presently is still reflecting both structural control (the igneous rocks at the central and southern parts of the coast) and the conditions which prevailed during the deposition and lithification of the sedimentary rocks occurring along this coastal segment.

The coastal segments analyzed above fit well with the general multiple-regression model presented in this dissertation. However, they are imbedded in the general computations which generated that model, i.e., other segments certainly contributed with greater departures from the general prediction equation for the occurrence of beaches along the South American coast. The residuals for the examples did not reach departures greater than 10 percent. The general fit, of course, can be estimated as poorer than that, inasmuch as the optimized multiple-regression statistic R^2 (see Table 1 of Appendix 3) was 67.7491. Aspects of the multiple regression scheme will be further dealt with.

The above considerations are indicative of the need for further research along the lines of this dissertation. Certainly other variables must be considered in studies of coastal segments at a larger cartographic scale. River sedimentary loads brought to the coast and nature and topography of the shelf contiguous to the coastal segments are some examples. One particular variable which seems to be difficult to quantify is represented by the geologic history of the area. The sequence of Quaternary events which occurred in a coast, for instance, is usually very important in the explanation of the geometric and geomorphologic characteristics of that coast. As a suggestion for investigations at a larger scale, an identification and some type of measurement possibly can be developed for inherited coastal features such as sequences of old beach ridges, recessed and stranded sea cliffs, and even stratigraphic sequences of deposited clastics of several origins.

In the eight analyzed segments the ratios and indexes developed in this study were applied as quantitative elements associated with each segment's descriptive account. Their formal association through statistical techniques designed to investigate internal relationships among them is next presented.

THE MULTIPLE-REGRESSION SCHEMES

The basic equation of the multiple linear regression schemes used in this work is as follows:

$$Y = b_o + b_1X_1 + b_2X_2 + \ldots + b_kX_k ,$$

in which Y is the dependent variable, X_1, X_2 . . . X_k are the independent variables, and b_o, b_1, b_2 . . . b_k are coefficients to be estimated. In the multiple-regression scheme of Table 1 (Appendix 3) the presence of beaches in the coastline segments of the coast of South America is associated with combinations of independent variables arranged in accordance with the adopted multiple linear regressive model above. The dependent variable, beaches in each coastline segment, is presented as a ratio between the coastline length of beaches (Beaches) and the entire length of the coastline segment (Arc). The independent variables include simple measurements (Spring Tide Range, Crenulations), ratios (Arc/Chord, Highland Coasts/Arc, Shore Shoals/Arc, Rocky Terraces/Arc), and a composite index (Wave $\cdot$ $\sqrt{\text{Chord/Arc}}$). All these final variables were discussed earlier in this study. Preliminary regression schemes are presented in Appendix 3 (Tables 2 and 3).

The facilities of the Computer Center of Louisiana State University were used for the final computations of this work. The General Foods Multiple Regression Program (MRP 49), available at the Center, was used to process the data. This program conducts a screening series of multiple regressions, starting with one including all the independent variables given as input.

Use of multiple linear regression schemes of the present type allows the selection of an optimized multiple-regression equation to explain the dependent variables. This is done through successive deletions of the least significant independent variable involved at each step of the analysis. The multiple-regression equations are recalculated after each deletion. At each step the value of the coefficient of determination (R^2), a measure of the fraction of the total variance of the dependent variable accounted for by the respective regression, is calculated. The relative contribution of each independent variable, X, to the variation of the dependent variable can be evaluated in terms of the reduction of R^2 resulting from the deletion of X. The deletion operation is repeated until R^2 undergoes a significant reduction, at which point the equation is considered to be optimized.

The essential features of the final regression scheme are presented in Table 1 (Appendix 3). The mean and the standard deviation of each variable are given under the heading "Summary Statistics" (Table 4, Appendix 3). The statistics presented under "Deletion Sequence" are R^2, the coefficient of determination; the Residual Mean Square, a measure of the unexplained variation contained in the regression; the Multiple F, a statistic which indicates the overall significance of the partial regression coefficients of the regressions calculated at each step (only the optimized regression equation, however, is shown on the tables); and the significant partial correlations present at each step of the regressive scheme, which are a measure of the correlation between the two specified independent variables, when the other independent variables are held constant (Snedecor and Cochran, 1967).

The statistics contined under "Deletion Sequence" are to be read, by rows, from the column containing the values of R^2. Each row represents a step of the regression scheme in which the regression equations and other statistics are calculated before each successive deletion of the least significant variable. The deleted variables and their associated F values are indicated between each row under the columns headed "Deleted Variable" and "F (at Deletion)."

CONCLUSIONS

1. Quantifying procedures for the study of some aspects of process-form interactions between terrestrial and marine forces, on a continental scale, are presented in this study. In a systematic investigation of the South American coast, standardized measurement techniques were developed to quantify the marine energy factors waves and tides; the landforms beaches, shoals, rocky terraces, highland and lowland coasts; and significant geometric characteristics of coastline configurations.

2. Indexes and ratios representative of the general interactions occurring among terrestrial and marine forces and related coastal landform responses, similar to those recognized in this study, are quantitative elements which can be used in association for descriptive analyses of process-landform relationships existing in large coastal segments.

3. The coastline of South America exhibits close association between the presence of beaches, on the one hand, and wave energy, tidal ranges, and the occurrence of crenulations, highlands, and shoals along the shoreline. This conclusion is supported by several elements contained in the screening regression scheme of Table 1 (Appendix 3). The regression can be considered optimized when the

coefficient of determination (R^2) is still high (67.7491), the Residual Mean Square is at a minimum (0.027631), the Multiple F statistic shows high significance (**) for the combination of independent variables, and the only two partial correlations present are not high (0.5844 and 0.3774). The presence of beaches along the South American coast is therefore associated with local geologic structures and lithologies, as indexed by crenulations and highland proximities, and with dynamic processes, of which the dispersion of deepwater wave energy as it migrates onshore is most important.

4. Marsden Squares were used as the basic framework for subdivision of the South American coastline into 43 segments. Thus, response features were sought in accordance with, basically, the variability of wave energy. This procedure allowed a closer inspection of the relations between deepwater wave energy and the occurrence of beaches, a landform by definition associated with wave activity at the coastline. It can be seen in Table 1 (Appendix 3) that the composite index Wave • $\sqrt{\text{Chord/Arc}}$ is the only independent variable with a positive coefficient in the regression equation. However, it must be noted that the wave energy at deep water, as expressed by the index Wave, by itself (that is, when not modified by the dispersion index $\sqrt{\text{Chord/Arc}}$), has practically no significance in explaining the presence of beaches along the coastline segments studied. Comparison of Tables 1 and 2

(Appendix 3) leads to this conclusion. In the regression scheme of Table 2, Wave was considered an independent variable by itself, and it had no significance at deletion. Quite oppositely, in Table 1, where the composite index Wave $\cdot \sqrt{\text{Chord/Arc}}$ is one of the independent variables, the wave energy modified by this dispersion factor was highly significant at deletion and had already participated in the optimized regression equation of the scheme. It is reasonable to conclude, from the present evidence, that the use of values for wave energy at deep water for the establishment of relations between coastal features and wave activity is an inadequate procedure. The effects of wave energy dispersion brought into these relationships by the configuration of the coast must be properly considered, regardless of the scale under which the investigation is being conducted. The present study covers a significant portion of the world's coastlines, the coast of an entire continent. Thus, its perspective differs from the common analytical procedures used to investigate the mechanisms of the involved phenomena, many of which are related only to data gathered at specific localities. Nevertheless, the importance of wave energy dispersion factors is also recognized in this study, and in this respect it is consistent with the results of studies found in the literature regarding wave energy dispersion effects caused by processes such as refraction, diffraction, percolation, bottom friction, etc. (Bretschneider and Reid, 1954; Hoyle and

King, 1958; Davies, 1959; Wiegel, 1964).

5. Two important geomorphic processes have relationships with the presence of beaches in the coastline segments studied. They are represented in the optimized equation of the regression scheme of Table 1 by the index Wave $\cdot$ $\sqrt{\text{Chord/Arc}}$ (with positive coefficient) and by the Spring Tide Range (with negative coefficient). Their effects toward the variation of the dependent variable Beaches/Arc are opposed, as shown by their different coefficient signs. Because both are contained in the same optimized equation of Table 1, and thus are connected to the explanation of the variability of beaches along the coastline, it can be proposed from the present analysis that increase in tidal range is generally accompanied by a decrease in the prevalence of beaches.

In addition to Spring Tide Range, the independent variables Crenulations and Highland Coasts/Arc also presented a negative coefficient in the optimized equation of Table 1. Thus, it can be concluded that large amounts of crenulations and highland coasts on the coasts studied are also associated with a small occurrence of beaches, mainly because they exclude the presence of these latter features. However, it seems also reasonable to assume, concerning the physical meaning of the mentioned negative associations, that when waves spend their energy attacking resistant cliffs or steep shores, instead of a movable bed of sediment, beaches will obviously be less prevalent. This case is exemplified in Figure 9.

The indicated negative association of Shore Shoals with the occurrence of beaches suggests that the abundance of shoals, particularly the ones constituted of fine clastics, is associated with the presence of the mouths of large rivers. Thus, the sediment load redistributed by waves and currents accumulates along the coast as shoals, which attenuate wave energy to such an extent as to reduce the occurrence of beaches. This situation is typical of the Guyana coast, where the sediments of the Amazon River are being redistributed over a large coastal area (see Fig. 5). This same zone also exemplifies the fact that the abundance of sediments may be coupled with the occurrence of large tidal ranges, resulting in extensive mudflats. Identifiable beaches, as defined in this study, may have only eventual and localized occurrences in coasts characterized by abundant supply of fine clastics and/or occurrence of large tidal ranges. In Table 5 of Appendix 3 it is shown that there are negative correlations between Beaches/Arc and both the Spring Tide Range (TSP) and Shore Shoals/Arc (SS/A).

6. The variables Rocky Terraces/Arc and Arc/Chord can be considered of practically no importance concerning the explanation of the presence of beaches in the coastal segments studied. They were the first variables to be deleted as least significant in the screening scheme of Table 1, and were nonsignificant when deleted (F at

deletion without asterisks). The reduction in the coefficient of determination R^2 was minor after both deletions (from 68.1877, when all the independent variables were considered, to 67.7491).

In the continental picture of the relations between beaches and the presence of rocky terraces, the influence of the latter was expected to be small because its occurrence, as registered in the 1:1,000,000 scale maps, is restricted to the Patagonian coast of Argentina.

As for the ratio Arc/Chord, its deletion without significance is interpreted as meaning that the amount of departure from a straight line displayed by the coastline segments, a coarse measure of their shape, has no importance, by itself, in the occurrence of beaches in these coastal segments. This situation could be expected because beaches are found along coastlines exhibiting variable shapes and consequently variable degrees of exposure to directions of wave approach.

7. Procedures adopted in this study, particularly the use of the large number of experimental units, the utilization of a single "resolution power" through standardized measures, and the use of screening statistical designs in analyses of internal relationships among the components of the problem, can be combined and become highly instrumental for the investigation of coastlines of continental dimensions.

Although a direct chain of causes and effects cannot emerge from this investigation, the limitations imposed by the type of information available seem to have been adequately bridged. Associative inferences stemming from analyses of large coastal extensions prevailed over accuracy in details. Maps or air photographs of scales similar to 1:1,000,000 can be used for the identification and measurement of important coastal features to be related to geomorphologic processes. A worldwide study of process-form relationships of the type presented in this investigation would generate significant basic information which would guarantee objectivity to the establishment of a meaningful classification of coasts.

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APPENDIX 1

LOCATION AND BRIEF DESCRIPTION OF THE COASTAL SEGMENTS

Segment No.	Location	Trend of Coast (Chord Direction)	1:1,000,000 Maps Used	Brief Description
1	Cabo Tiburon (border Panama-Colombia) to Punta Balilla (75 degrees West)	N46E	NB-18 and NC-18	Northwestern coast of Colombia, which includes the Gulf of Uraba and some spurs from the western branch of the Andes reaching the coast-line.
2	Punta Balilla (75 degrees West) to Cabo de la Vela (near 72 degrees West)	N67E	NC-18	Coast of northern Colombia. Includes the Magdalena River delta complex and the extension of one of the northern branches of the Andes into the coastal zone.
3	Cabo de la Vela (near 72 degrees West) to Puerto Cabello (near 68 degrees West)	N89W	NC-18, NC-19, and NC-20	Northwestern coast of Venezuela, which includes the Gulf of Venezuela. Lake Maracaibo shoreline is not included in this segment length.
4	Puerto Cabello (near 68 degrees West) to Punta Escarceo (near 64 degrees West)	N87E	NC-19 and NC-20	Venezuelan coast compre-hending the mountainous around Caracas, lowlands and highlands eastward from it.

(Continued)

Segment No.	Location	Trend of Coast (Chord Direction)	1:1,000,000 Maps Used	Brief Description
5	Punta Escarceo (near 64 degrees West) to Punta Penas (near 62 degrees West)	N88E	NC-20	Mountainous coast northwest of the Orinoco delta.
6	Punta Penas (near 62 degrees West) to Punta Playa (near 60 degrees West)	N41W	NC-20	Mostly the low coast of the Orinoco delta.
7	Punta Playa (near 60 degrees West) to Nickerie-punt (near 57 degrees West)	N49W	NC-20 and NB-21	Low, mudflat- and mangrove-rich British Guiana coast.
8	Nickerie-punt (near 57 degrees West) to Valsch Braamspunt (near 55 degrees West)	N89E	NB-21	Western part of the low, mudflat- and mangrove-rich coast of Suriname.
9	Valsch-Braamspunt (near 55 degrees West) to Pointe Behague (near 52 degrees West)	N68W	NB-21 and NB-22	Low, mudflat- and mangrove-rich coast from near Paramaribo to Pointe Behague, east of Cayenne.

(Continued)

Segment No.	Location	Trend of Coast (Chord Direction)	1:1,000,000 Maps Used	Brief Description
10	Pointe Behague (near 52 degrees West) to Cabo Norte (near 50 degrees West)	N33W	NA-22 and NB-22	The muddy, low, and mangrove-rich Guyana coast, mostly the Brazilian part, nearer the Amazon mouth.
11	Cabo Norte (near 50 degrees West) to limit of the map SA-22 (48 degrees West)	N39W	NA-22 and SA-22	The low coast of the Amazon mouths and Marajo Island.
12	Barreto River (limit of the map) (48 degrees West) to Ponta do Mangue (43 degrees 30 minutes West)	N70W	SA-23	The low, highly articulated coast of Maranhao.
13	Ponta do Mangue (near 40 degrees West) to Farol de Tapage (near 40 degrees West)	N73W	SA-23 and SA-24	Typical coast of beaches and dunes of the State of Maranhao, the Parnaiba delta complex, and the low coast of the State of Ceara, Brazil.

(Continued)

Segment No.	Location	Trend of Coast (Chord Direction)	1:1,000,000 Maps Used	Brief Description
14	Farol de Tapage (near 40 degrees West) to Cabo de Sao Roque (near 35 degrees West)	N61W	SA-24, SB-24, and SB-25	Typical low coast, rich in dunes, reefs, and beaches, of northeastern Brazil.
15	Cabo de Sao Roque (near 35 degrees West) to Olinda (near 8 degrees South)	N10W	SB-25	Coast of reefs and beaches of northeastern Brazil, just north of Recife.
16	Olinda (near 8 degrees South) to Farol da Barra (near 13 degrees South)	N36E	SC-25, SC-24, and SD-24	Low coast rich in reefs and beaches of northeastern Brazil, which includes the Sao Francisco delta.
17	Farol da Barra (Salvador, near 13 degrees South) to Ponta dos Lencois (near 18 degrees South)	N12E	SD-24 and SE-24	North-south trending eastern coast of Brazil.

(Continued)

Segment No.	Location	Trend of Coast (Chord Direction)	1:1,000,000 Maps Used	Brief Description
18	Punta dos Lencois (near 18 degrees South) to the point nearest Arraial do Cabo (near 23 degrees South)	N23E	SE-24 and SF-24	Continuation of the eastern coast of Brazil, which includes the deltas of the Doce and Paraiba do Sul rivers. Spurs from the Brazilian eastern highlands reach the coast of this segment.
19	From the point nearest Arraial do Cabo (near 23 degrees South) to Ponta de Itacurussa (near 25 degrees South)	N69E	SF-24, SF-23, and SG-23	This coastline trends approximately east-west in southeastern Brazil; comprises the mountainous coast near Rio de Janeiro and Santos.
20	Ponta de Itacurussa (near 25 degrees South) to Ponta do Pinheiro (near 28 degrees South)	N13E	SG-22 and SG-23	Mountainous coast of southeastern Brazil.

(Continued)

Segment No.	Location	Trend of Coast (Chord Direction)	1:1,000,000 Maps Used	Brief Description
21	Ponta do Pinheiro (near 28 degrees South) to Beira - Mar (near 32 degrees South)	N36E	SG-22, SH-22, and SI-22	Coast in part characterized by mountains and southward by the long, straight beaches of the State of Rio Grande do Sul.
22	Beira - Mar (near 32 degrees South) to Cabo Polonio (near 34 degrees South)	N33E	SI-22	Very smooth low coast of the southernmost Brazilian coast, famous for its extensive beaches and coastal lagoons.
23	Cabo Polonio (near 34 degrees South) to Faro Medanos (near 37 degrees South)	N43E	SI-21, SI-22, and SJ-21	Comprises all of the La Plata estuary.
24	Faro Medanos (near 37 degrees South) to Punta Rasa (near 41 degrees South)	N47E	SJ-20, SJ-21, and SK-20	Low coast south of the La Plata estuary, which includes the Bahia Blanca coastline.

(Continued)

Segment No.	Location	Trend of Coast (Chord Direction)	1:1,000,000 Maps Used	Brief Description
25	Punta Rasa (near 41 degrees South) to Cabo Dos Bahias (near 45 degrees South)	N30E	Sk-20 and SL-19	Central-eastern Argentinian coast, which includes the Gulf of S. Matias and the Peninsula Valdes and is reached by the highlands of the Meseta de Montemayor.
26	Cabo Dos Bahias (near 45 degrees South) to C. S. Francisco de Paula (near 50 degrees South)	N18E	SL-19, SM-18, and SM-19	Part of the Patagonian coast of Argentina.
27	C. S. Francisco de Paula (near 50 degrees South) to Cabo San Diego (near 54 degrees 40 minutes South)	N17W	SM-18, SM-19, and SN-19	Southern Argentinian coast, which includes the Magellan Strait and the eastern coast of the Tierra Del Fuego.
28	Cabo San Diego (near 54 degrees 40 minutes South) to Cabo York Minster (70 degrees West)	N74E	SN-19	Mountainous, highly articulated southern coast of Tierra Del Fuego.

(Continued)

Segment No.	Location	Trend of Coast (Chord Direction)	1:1,000,000 Maps Used	Brief Description
29	Cabo York Minster (near 70 degrees West) to Cabo Deseado (near 74 degrees 40 minutes West)	N48W	SN-19	Mountainous, highly articulated southwestern coast of Tierra Del Fuego.
30	Cabo Deseado (near 74 degrees West) to Cabo Hawksworth (near 50 degrees South)	N09W	SN-19, SM-18, and SM-19	Mountainous, highly articulated southern coast of Chile, from Strait of Magellan north.
31	Cabo Hawksworth (near 50 degrees South) to Punta Guala (near 44 degrees South)	N08E	SM-18, SM-19, SL-18, SK-18, and SK-19	Mountainous, highly articulated southern coast of Chile.
32	Punta Guala (near 44 degrees South) to Punta Colun (near 40 degrees South)	N08W	SK-18 and SK-19	Mountainous, highly articulated southern coast of Chile.

(Continued)

Segment No.	Location	Trend of Coast (Chord Direction)	1:1,000,000 Maps Used	Brief Description
33	Punta Colun (near 40 degrees South) to Punta Cardonal (near 35 degrees South)	N12E	SK-18, SK-19, SJ-18, SJ-19, and SI-18	Mountainous coast of central Chile.
34	Punta Cardonal (near 35 degrees South) to Punta Lengua de Vaca (near 30 degrees South)	N06E	SH-19, SI-18, and SI-19	Mountainous coast of central Chile.
35	Punta Lengua de Vaca (near 30 degrees South) to the northern coastline limit on the map (28 degrees South)	N11E	SH-19	Mountainous north-central coast of Chile.
36	Limits of map (28 degrees South) to 24 degrees South	N09E	SG-19	Mountainous northern Chilean coast south of Antofagasta.
37	24 degrees South (limit of map) to 20 degrees South (limit of map)	N05E	SF-19	Mountainous northern Chilean coast, north of Antofagasta.

(Continued)

Segment No.	Location	Trend of Coast (Chord Direction)	1:1,000,000 Maps Used	Brief Description
38	20 degrees South (limit of map) to Cabo Nascar (near 15 degrees South)	N46W	SE-19 and SD-18	Mountainous coast of southern Peru.
39	Cabo Nascar (near 15 degrees South) to Punta Culebras (near 10 degrees South).	N28W	SC-17, SC-18, and SD-18	Typical mountainous central coast of Peru, which includes Lima.
40	Punta Culebras (near 10 degrees South) to Nermete (near 5 degrees South)	N31W	SB-17 and SC=17	Mountainous northern coast of Peru.
41	Nermete (near 5 degrees South) to Cabo S. Lorenzo (near 1 degree South).	N03E	SA-17 and SB-17	Mainly the Ecuadorian coast, where extensions of the Andean Cordillera are interspersed with coastal plains.

(Continued)

Segment No.	Location	Trend of Coast (Chord Direction)	1:1,000,000 Maps Used	Brief Description
42	Cabo S. Lorenzo (near 1 degree South) to I. de Gallo (near 2 degrees North)	N37E	SA-17 and NA-17	Comprehends the northern Ecuadorian coast and a small portion of the southern Colombian coast, where sparse projections of the Andean Cordillera reach the sea.
43	I. de Gallo (near 2 degrees North) to limit Colombia X Panama (near 7 degrees North)	N08E	NB-18, NA-18, and NA-17	Pacific coast of Colombia, where some isolated highlands reach the sea.

APPENDIX 2

NUMERIC VALUES OF VARIABLES

Features	Segments 1	2	3	4	5	6	7	8
Geometric Characteristics								
Arc	494.30	259.08	812.21	440.18	194.14	470.14	315.36	150.86
Chord	229.18	211.34	305.48	225.48	162.84	193.77	265.29	129.57
Crena	63	23	93	89	79	28	22	20
Arc/Chord	2.16	1.23	2.66	1.72	1.19	2.43	1.19	1.16
$\sqrt{\text{Chord/Arc}}$	0.68	0.90	0.61	0.72	0.92	0.64	0.92	0.93
Energy Factors								
Wave	115.57	105.25	86.12	73.26	71.52	81.94	84.84	95.96
Wave $\cdot$ $\sqrt{\text{Chord/Arc}}$	78.59	94.73	52.53	52.75	65.80	52.44	78.05	89.24
TM*	1.00	1.00	1.40	1.00	1.00	4.00	6.20	6.55
TSP	1.50	1.50	1.80	1.50	1.50	4.90	8.15	8.25
Coastal Landforms								
HC	97.67	53.49	50.49	259.12	137.66	33.34	-	-
LC	394.57	203.22	743.13	172.81	56.83	436.16	315.36	150.86
Beaches	313.25	208.56	350.14	146.23	45.67	180.24	83.51	8.15
SS	-	-	-	-	-	-	119.41	100.12
RT	-	-	-	-	-	-	-	-

*Explanation of abbreviations: TM = Mean Tide Range; TSP = Spring Tide Range; HC = Highland Coasts; LC = Lowland Coasts; SS = Shore Shoals; RT = Rocky Terraces.

(Continued)

Features	Segments							
	9	10	11	12	13	14	15	16
Geometric Characteristics								
Arc	300.59	352.86	767.31	1609.83	320.88	433.45	191.73	470.99
Chord	240.10	241.49	214.42	332.67	242.94	371.11	174.96	425.80
Crena	25	23	81	364	35	34	19	28
Arc/Chord	1.25	1.46	3.58	4.83	1.32	1.17	1.10	1.11
$\sqrt{\text{Chord/Arc}}$	0.89	0.83	0.53	0.45	0.87	0.92	0.96	0.95
Energy Factors								
Wave	97.20	71.56	58.71	58.92	77.81	74.59	80.48	52.09
Wave $\cdot \sqrt{\text{Chord/Arc}}$	86.51	59.39	31.12	26.51	67.69	68.62	77.26	49.48
TM	6.05	14.50	8.40	12.50	11.00	6.60	5.20	5.20
TSP	7.50	19.00	9.50	15.90	13.50	8.45	6.65	6.65
Coastal Landforms								
HC	-	-	-	-	-	-	-	14.78
LC	300.59	352.86	767.31	1609.83	320.88	433.45	191.73	465.94
Beaches	19.39	26.73	20.66	20.68	218.49	364.17	125.21	341.98
SS	116.96	111.54	140.72	40.72	69.02	30.26	4.21	22.14
RT	-	-	-	-	-	-	-	-

(Continued)

Features	Segments 17	18	19	20	21	22	23	24
Geometric Characteristics								
Arc	811.76	431.09	728.90	538.60	380.98	190.78	636.49	662.25
Chord	373.07	352.85	402.78	202.53	362.81	183.30	236.12	414.22
Crena	133	52	172	137	15	6	61	63
Arc/Chord	2.18	1.22	1.81	2.66	1.05	1.04	2.70	1.60
$\sqrt{\text{Chord/Arc}}$	0.67	0.91	0.74	0.61	0.98	0.98	0.61	0.79
Energy Factors								
Wave	82.93	89.13	96.71	101.88	114.82	138.22	100.68	120.48
Wave $\cdot$ $\sqrt{\text{Chord/Arc}}$	55.56	81.11	71.56	62.15	112.52	135.46	61.41	95.18
TM	5.20	2.45	2.45	2.45	2.45	2.45	2.45	16.00
TSP	6.65	3.60	3.60	3.60	3.60	3.60	3.60	18.00
Coastal Landforms								
HC	80.66	22.89	326.98	169.55	8.87	-	-	-
LC	731.10	408.19	411.12	353.98	373.14	190.78	636.49	662.25
Beaches	213.91	258.75	316.12	150.97	364.52	188.13	252.42	138.95
SS	-	5.92	-	-	-	-	204.21	330.13
RT	-	-	-	-	-	-	-	-

(Continued)

Features	Segments							
	25	26	27	28	29	30	31	32
Geometric Characteristics								
Arc	852.71	617.88	849.43	997.71	1357.10	2106.36	3511.72	744.67
Chord	323.73	348.55	363.32	201.98	265.45	188.84	454.31	257.82
Crena	124	103	100	349	419	600	735	201
Arc/Chord	2.63	1.77	2.34	4.94	5.11	11.15	7.73	2.89
$\sqrt{Chord/Arc}$	0.62	0.75	0.65	0.45	0.44	0.30	0.34	0.59
Energy Factors								
Wave	119.76	126.40	116.66	180.88	185.56	188.65	180.05	128.83
Wave $\cdot$ $\sqrt{Chord/Arc}$	74.25	94.80	75.83	81.40	81.65	71.69	61.42	76.01
TM	19.95	16.40	22.40	4.80	4.25	4.60	4.60	11.10
TSP	24.55	18.45	27.70	5.35	5.10	5.90	5.90	13.80
Coastal Landforms								
HC	84.88	120.06	176.65	903.14	1296.77	2018.54	3294.80	433.71
LC	767.54	497.15	668.00	94.57	60.33	145.62	292.67	310.17
Beaches	260.44	254.02	49.07	39.49	39.53	18.04	63.35	131.46
SS	101.81	39.40	365.50	-	-	-	66.85	-
RT	-	43.32	162.22	17.15	-	-	-	-

(Continued)

Features	Segments							
	33	34	35	36	37	38	39	40
Geometric Characteristics								
Arc	515.81	386.44	226.38	354.81	351.34	604.33	500.76	505.51
Chord	369.62	318.62	156.88	278.83	278.59	498.26	393.20	394.93
Crena	96	134	116	145	96	184	133	100
Arc/Chord	1.40	1.21	1.44	1.27	1.26	1.21	1.27	1.28
$\sqrt{\text{Chord/Arc}}$	0.84	0.91	0.83	0.89	0.89	0.91	0.89	0.88
Energy Factors								
Wave	117.47	101.97	76.46	83.36	75.51	70.05	63.14	57.57
Wave · $\sqrt{\text{Chord/Arc}}$	98.67	92.79	63.46	74.19	67.20	63.74	56.19	50.66
TM	4.30	3.50	3.50	3.50	3.50	3.25	3.25	3.25
TSP	5.45	5.00	5.00	5.00	5.00	4.20	4.20	4.20
Coastal Landforms								
HC	268.85	117.26	163.15	317.57	331.54	535.23	234.25	109.83
LC	232.71	113.69	60.69	35.08	15.41	64.95	262.03	390.71
Beaches	332.83	169.13	95.33	86.88	113.09	291.35	247.65	360.32
SS	-	-	-	-	-	-	-	-
RT	-	-	-	-	-	-	-	-

(Continued)

Features	Segments 41	42	43
Geometric Characteristics			
Arc	500.91	468.46	732.68
Chord	276.42	263.47	364.54
Crena	82	52	110
Arc/Chord	1.81	1.78	2.01
$\sqrt{\text{Chord/Arc}}$	0.74	0.75	0.70
Energy Factors			
Wave	55.70	61.56	37.24
Wave • $\sqrt{\text{Chord/Arc}}$	41.22	46.17	26.07
TM	11.10	7.15	9.30
TSP	13.80	9.00	11.60
Coastal Landforms			
HC	81.95	99.59	158.96
LC	419.32	372.96	572.04
Beaches	247.29	171.83	120.00
SS	-	-	118.12
RT	-	-	-

APPENDIX 3

REGRESSIVE SCHEMES AND CORRELATIONS

Table 1

Regression of Beaches/Arc on A/C, Crena, TSP,

HC/A, SS/A, RT/A, and Wave • $\sqrt{C/A}$

Deletion Sequence					
Deleted Variable	F (At Deletion)	R^2 (%)	Residual M. S.	Multiple F	Significant Partial Correlations Among the Indep. Variables Present before each Deletion
		68.1877	.028812	10.7172**	A/C & Crena** (.8726); Crena & HC/A** (.5019); TSP & HC/A** (-.3922); TSP & RT/A** (.5656). Total = 4
1) RT/A	.0041(NS)				
		68.1840	.028015	12.8584**	A/C & Crena** (.8723); Crena & HC/A** (.4879); TSP & SS/A* (.3829). Total = 3
2) A/C	.4921(NS)				
		67.7491	.027631	15.5451**	Crena & HC/A** (.5844); TSP & SS/A* (.3774). Total = 2
Optimized Multiple-Regression Equation Beaches/Arc = .48546 + .00358** (Wave • $\sqrt{C/A}$) - .00068** Crena - .30311** HC/A - - .9221** SS/A - .01146* TSP					
3) TSP	5.2430*				
		63.1791	.030716	16.3005**	Crena & HC/A** (.5536); HC/A & SS/A** (-.4352). Total = 2

(Continued)

Deleted Variable	F (At Deletion)	R^2 (%)	Residual	Multiple	Significant Partial Correlations Among the Indep. Variables Present before each Deletion
4) HC/A	4.7594*				
		58.5674	.033676	18.3762**	ZERO
5) $W \cdot \sqrt{C/A}$	7.8437**				
		50.2344	.039439	20.1884**	ZERO
6) SS/A	20.4876**				
		24.7450	.058184	13.4814**	ZERO
7) Crena	13.4814**				

Table 2

Regression of Beaches/Arc on A/C, Crena, Wave,

TSP, HC/A, SS/A, RT/A

Deletion Sequence					
Deleted Variable	F (At Deletion)	R^2 (5)	Residual M. S.	Multiple F	Significant Partial Correlations Among the Indep. Variables Present before each Deletion
		65.4441	.031297	9.4693**	A/C & Crena** (.8092); Crena & HC/A** (.4848); TSP & HC/A* (-.3745); TSP & RT/A** (.5594). Total = 4
1) RT/A	.00047(NS)				
		65.4436	.030428	11.3629**	A/C & Crena** (.8189); Crena & HC/A** (.4689); TSP & SS/A* (.3691).
2) Crena	.6812(NS)				
		64.7897	.030166	13.6166**	A/C & Wave** (.5608); HC/A & SS/A* (.3663); TSP & SS/A* (.3532).
3) Wave	3.6908(NS)				
		61.2774	.032302	15.0334**	A/C & HC/A** (.4315); TSP & SS/A (.3546); HC/A & SS/A* (-.3457).

(Continued)

Deleted Variable	F (At Deletion)	R^2 (%)	Residual M. S.	Multiple F	Significant Partial Correlations Among the Indep. Variables Present before each Deletion
Optimized Multiple-Regression Equation Beaches/Arc = .8030 - .08003** SS/A - .3570** HC/A - .0551** A/C - .0142* TSP					
4) TSP	7.2626*				
		53.8767	.037490	15.1853**	A/C & HC/A** (.3999); HC/A & SS/A** (-.4809).
5) HC/A	7.1860*				
		45.3782	.043287	16.6154**	ZERO
6) SS/A	13.7528**				
		26.5981	.056752	14.8569**	ZERO
7) A/C	14.8569				

Table 3

Regression of Beaches on Arc, Chord, Crena, Wave,

TM, TSP, HC, LC, SS, RT

Deleted Variable	F (At Deletion)	R^2 (%)	Residual M. S.	Multiple F	Significant Partial Correlations Among the Indep. Variables Present before each Deletion
		Deletion Sequence			
		76.384	4046.46	10.350**	Arc & Crena* (.3865); Arc & HC** (.9957); Arc & LC** (.9964); Crena & SS* (-.3948); TM & TSP** (.9939); HC & LC** (-.9971). Total = 6
1) TM	.0027(NS)				
		76.382	3924.17	11.858**	Arc & Crena (.3864); Arc & HC** (.9957); Arc & LC** (.9964); Crena & LC* (-.3340); Crena & SS* (-.3968); TSP & SS* (.4050); HC & LC** (-.9972). Total = 7
2) RT	.0726(NS)				
		76.330	3817.14	13.705**	Arc & Crena* (.3900); Arc & HC** (.9957); Arc & LC** (.9965); Crena & SS* (-.4100); Crena & LC* (-.3382); TSP & SS** (.5626); HC & LC** (-.9972). Total = 7
3) Arc	.2014(NS)				

Deleted Variable	F (At Deletion)	R^2 (%)	Residual M. S.	Multiple F	Significant Partial Correlations Among the Indep. Variables Present before each Deletion
		76.190	3730.05	15.999**	Crena & HC** (.9163); Crena & LC** (.6562); Crena & SS* (-.4153); TSP & SS** (.5597); HC & LC** (-.6373); HC & SS* (.3463); LC & SS** (.3429). Total = 7
4) TSP	1.8775(NS)				
		74.91	3820.97	17.917**	Crena & SS* (-.3948); Crena & HC** (.9138); Crena & LC** (.6910); HC & LC** (-.6760); LC & SS** (.4998). Total = 5
5) HC	3.2382(NS)				
		72.66	4052.12	19.663**	Crena & Wave** (.6944); Wave & LC* (-.3541); LC & SS** (.4231). Total = 3

Optimized Multiple Regression Equation
Beaches = .896** Chord - .611** Crena - .781** SS + 1.31** Wave + .084 LC* - 132.616

6) LC	4.2506*				
		69.52	4398.75	21.663**	Chord & Arc* (.3414); Crena & Wave** (.6703). Total = 2
7) Wave	7.4234**				

Deleted Variable	F (At Deletion)	R^2 (%)	Residual M. S.	Multiple F	Significant Partial Correlations Among the Indep. Variables Present before each Deletion
		.6356	5123.23	22.675**	ZERO
8) SS	20.1927**				
		.4469	7581.45	16.161**	ZERO
9) Crena	14.481**				
		.2467	10074.34	13.426**	ZERO
10) Chord	13.429**				

Table 4

Summary Statistics

Variable	Mean	St. Deviation
Beaches/Arc	0.3660	0.2747
A/C (Arc/Chord)	2.2893	1.9389
Crena (Crenulations)	128.9302	151.3854
TSP (Spring Tide Range)	7.9465	6.2058
HC/A (Highland Coasts/Arc)	0.3493	0.3502
SS/A (Shore Shoals/Arc)	0.0914	0.1652
RT/A (Rocky Terraces/Arc)	0.0065	0.0307
Wave $\cdot \sqrt{C/A}$ (Composite Index)	69.7058	21.7312
Wave (Deepwater Wave Energy Index)	96.6858	36.5593
Beaches	173.2030	114.2586
Arc	654.6455	584.3074
Chord	291.1934	89.3476
Crena	128.9302	151.3854
TM (Mean Tide Range)	6.3070	5.2089
TSP (Spring Tide Range)	7.9465	6.2058
HC (Highland Coasts)	280.5168	602.8957
LC (Lowland Coasts)	373.4468	288.2872
SS (Shore Shoals)	46.2102	84.6394
RT (Rocky Terraces)	5.1788	25.5104

Table 5

Simple Correlations

	Beaches/Arc	A/C	Crena	TSP	HC/A	SS/A	RT/A	Wave$\cdot\sqrt{C/A}$
Beaches/Arc	1.0000	-.5157	-.4974	-.3917	NS	-.3501	NS	.3368
A/C		1.0000	.8906	NS	.4186	NS	NS	NS
Crena			1.0000	NS	.5943	NS	NS	NS
TSP				1.0000	-.3753	.4762	.5545	NS
HC/A					1.0000	-.4952	NS	NS
SS/A						1.0000	NS	NS
RT/A							1.0000	NS
Wave$\cdot\sqrt{C/A}$								1.0000

VITA

Jorge Xavier da Silva was born at Rio de Janeiro, Guanabara, Brazil, September 17, 1935. He attended Moderna Associacao Brasileira de Ensino, a high school in that city. He enrolled in the Faculdade Nacional de Filosofia of the Universidade do Brazil, in Rio, and received the degrees Bachelor and Licensee in Geography in 1959. In 1957 he began working at the Conselho Nacional de Geografia, Instituto Brasileiro de Geografia e Estatistica. He began his graduate studies at Louisiana State University in September, 1961, and received his Master of Science degree in Geography in June, 1963.

Returning to Brazil, he started his university teaching career at the Universidade do Estado da Guanabara. In 1965 he entered the Universidade Federal do Rio de Janeiro (former Universidade do Brasil) as Assistant Professor. During the year 1968 he was Associate Director for Undergraduate Affairs of the Instituto de Geociencias da Universidade Federal do Rio de Janeiro. In January, 1969, he resumed his studies leading to the Ph.D. degree.

He is a member of the Associacao dos Geografos Brasileiros, the Sociedade Brasileira de Geologia, the honor society Phi Kappa Phi, the Graduate Program

Committee of his Department of Geography, and also a corresponding member of the Subcommission on American Shorelines of the International Association for Quaternary Research.

EXAMINATION AND THESIS REPORT

Candidate: Jorge Xavier da Silva

Major Field: Geography

Title of Thesis: Processes and Landforms in the South American Coast

Approved:

Wm G. McIntire
Major Professor and Chairman

Max Goodrich
Dean of the Graduate School

EXAMINING COMMITTEE:

Robert C. West

Prentiss E. Schilling

J. M. Coleman

S. M. Gagliano

Date of Examination:

February 4, 1971